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Dual Process High-Rate Filtration of Raw Sanitary Sewage and Combined Sewer Overflows

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16. ABSTRACT

Pilot plant studies were conducted at New York's Newtown Creek Water Pollution Control Plant from 1975-1977 to to investigate the suspended solids (SS) removal capabilities of the deep bed, high rate gravity filtration process on raw sewage and combined sewer overflows.

The treatment system was composed of a rotating screen equipped with a 40 mesh (420 micron) screen followed by a dual media, high rate filter containing 48 in, (122 cm) or 60 in. (152 cm) of No. 3 anthracite (effective size 3.85 mm) over 30 in. (76 cm) of NO. 612 sand (effective size 2mm).

A continuous series of tests on dry weather (raw sewage) flows demonstrated SS removals across the filter averaging 67 percent at flux ranging 8-12 gpm/ft^2 (20-30 m^3/hr/m^2) with an average effluent of 44 mg/l. BOD and COD removals were 39 percent and 34 percent, respectively.

Tests on combined sewer overflow and average removal of 61 percent SS across the filter and 66 percent across the system at a flux of 16 gpm/ft^2 (40 m^3/hr/m^2) and and average effluent of 62 mg/l SS. BPD and COD removals across the filter were 32 percent and 42 percent, respectively. The addition of cationic polymer (1.3,2 mg/l) combination with alum (17,35 mg/l) improved filter removals to an average 72 percent for SS, 40 percent for BOD and 50 percent for COD for two tests.

Capital costs (ENR-2520) for a high rate filtration plant are estimated at $55,225 per mgd for a 200 mgd plant (757,000 m^3/day). Total annual treatment costs, including amortization, operation and maintenance charges, range from approximately $396,450 to $1,794,050 for dual treatment facilities in a 25 to 200 mgd (94,600 to 757,000 m^3/day) capacity range and $238,050 to $1,175,900 for the same capacity range of facilities treating only CSO.

Comparison with alternative treatment systems show that HRF is cost competitive with conventional sedimentation facilities for dual-process or CSO treatment yet HRF has on 5-7 percent the area requirements. For strict CSO treatment, HRF is competitive with dissolved air flotation and microstraining processes.

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DUAL PROCESS HIGH-RATE FILTRATION OF RAW SANITARY SEWAGE AND COMBINED SEWER OVERFLOWS

by

Hank Innerfeld
Angelika Forndran
New York City Department of Water Resources
New York, New York 10013

Dominick D. Ruggiero
Thomas J. Hartman
Nebolsine Kohlmann Ruggiero Engineers, P.C.
New York, New York 10022

Grant No. S-803271

Project Officers

Richard Field
Richard P. Traver
Storm and Combined Sewer Section
Wastewater Research Division
Municipal Environmental Research Laboratory (Cincinnati)
Edison, New Jersey 08817

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
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CINCINNATI, OHIO 45268

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The deleterious effects of combined sewer overflows upon the nation's waterways have become of increasing concern in recent times. This report presents the results of a two-year testing program of pilot plant high-rate filtration for treating combined sewer overflows and sanitary sewage.

Francis T. Mayo
Director
Municipal Environmental
Research Laboratory

ABSTRACT

Pilot plant studies were conducted in New York's Newtown Creek Water Pollution Control Plant from 1975-1977 to investigate the suspended solids (SS) removal capabilities of the deep bed, high rate gravity filtration process on raw sewage and combined sewer overflows.

The treatment system was composed of a rotating screen equipped with a 40 mesh (420 micron) screen followed by a dual media, high rate filter containing 48 in. (122 cm) or 60 in. (152 cm) of No. 3 anthracite (effective size 3.85 mm) over 30 in. (76 cm) of No. 612 sand (effective size 2 mm).

A continuous series of tests on dry weather (raw sewage) flows demonstrated SS removals across the filter averaging 67 percent at a flux range of 8-12 gpm/ft^2 (20-30 m^3/hr/m^2) with an average effluent concentration of 44 mg/l SS. BOD and COD removals were 39 percent and 34 percent, respectively.

Tests on combined sewer overflow showed an average removal of 61 percent SS across the filter and 66 percent across the system at a flux of 16 gpm/ft^2 (40 m^3/hr/m^2) and an average effluent of 62 mg/l SS. BOD and COD removals across the filter were 32 percent and 42 percent, respectively. The addition of cationic polymer (1-2 mg/l) in combination with alum (17-35 mg/l) improved filter removals to an average 72 percent for SS, 40 percent for BOD and 50 percent for COD for two tests.

Capital costs (ENR-2520) for a high rate filtration plant are estimated at \$55,225 per mgd for a 200 mgd plant (757,000 m^3/day). Total annual treatment costs, including interest amortization, operation and maintenance charges, range from approximately \$396,450 to \$1,794,050 for dual treatment facilities in a 25 to 200 mgd (94,600 to 757,000 m^3/day) capacity range and \$238,050 to \$1,175,900 for the same capacity range of facilities treating only CSO.

Comparison with alternate treatment systems show that high rate filtration (HRF) is cost competitive with conventional sedimentation facilities for dual-process or CSO treatment yet HRF has only 5-7 percent the area requirements. For strict CSO treatment, HRF is competitive with dissolved air flotation and microstraining processes.

This report was submitted in fulfillment of Grant No. S 803271 by New York City, Department of Water Resources; and Nebolsine Kohlmann Ruggiero Engineers, P.C. under the sponsorship of the U.S. Environmental Protection Agency. This report covers plant construction and evaluation performed during the period June 1, 1975 to June 30, 1977; all work was completed as of July 1, 1978.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

BOD -- biochemical oxygen demand, five day

COD -- chemical oxygen demand

CSO -- combined sewer overflow

ENR -- Engineering News Record

FBOD -- filtrate BOD

FCOD -- filtrate COD

FC -- fecal coliform

HRF -- high rate filtration, high rate filter

mgd -- million gallons per day

PVC -- polyvinyl chloride

RDWS -- raw dry weather sewage

SDI -- sludge density index = $\frac{\text{mg/l of suspended matter}}{\text{ml of settled sludge x 10}}$

SVI -- sludge volume index = $\frac{100}{\text{SDI}}$

SS -- suspended solids

TEFC -- totally enclosed fan cooled

UBOD -- ultimate BOD

VSS -- volatile SS

SYMBOLS

Cl_2 -- chlorine

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SECTION 1

INTRODUCTION

Combined sewer overflows (CSO) and non-point source runoff caused during rainfall are significant sources of water pollution (1). These high volume, short term events send concentrated pollutants into receiving waters, degrading the water quality.

In recent years a variety of systems and treatment processes have been tested for the control and treatment of CSO. Any system or facility designed for retention and/or treatment of CSO should include automatic startup, be flexible in capacity, and reliable. A system designed only to control CSO would operate on a stand-by basis and be idle for significant periods of time, tending to be less cost-effective than a system which could treat both dry weather and wet weather flows throughout the year.

Such a dual-treatment system utilizing high rate filtration (HRF) technology was evaluated under the project discussed herein (USEPA demonstration grant S 803271) by the City of New York and Nebolsine Kohlmann Ruggiero Engineers, P.C. (NKRE), using a dual media HRF.

The tests were performed on a 30 in. (76 cm) diameter gravity filter column containing 48 in. (122 cm) or 60 in. (152 cm) of No. 3 anthracite over 30 in. (76 cm) of No. 612 sand. The filter was preceded by a rotary screening unit equipped with a 40 mesh (420 micron) screen to remove grit, fibers and other coarse material which could clog the filter and reduce the length of filter runs. Testing was performed both with and without the use of chemical additives at a flux range of 8-24 gpm/ft^2 (20-60 m^3/hr/m^2).

HISTORY

HRF has been developed over the past 15 years and used for a variety of treatment applications, chiefly in industrial wastewater treatment. A 2 mgd (7570 m^3/day) plant is currently being used in sewage treatment for effluent polishing in Ashvale, England (2) at a flux range of 8-12 gpm/ft^2 (20-30 m^3/hr/m^2). Another HRF polishing system is under construction in Como Italy, as part of a new 10 mgd (37,850 m^3/day) secondary treatment plant; the design flux is 15 gpm/ft^2 (37 m^3/hr/m^2).

Several pilot plant studies of HRF for both CSO and dry-weather municipal flows have recently been completed. Studies at Rochester, N.Y. (3) used parallel 6-in. (15 cm) pressurized dual media filters at a flux range of 10-24 gpm/ft^2 (25-60 m^3/hr/m^2) with and without chemicals. A primary swirl solids concentration system treated the CSO ahead of the filters. A previous study at Syracuse (4) used CSO pretreated by fine screening and reported suspended solids (SS) mass removals of 43-91 percent at a flux range of 10-13 gpm/ft^2 (25-32 m^3/hr/m^2) with 50-220 mg/l doses of alum and 1-4 mg/l doses of polymer filtration aids. A study in Minnesota (5) utilized natural and simulated stormwater in 20-in. (51 cm) diameter dual media pressurized filters and reported average SS removals of 63 percent with polymers and 51-58 percent without chemicals at a flux range of 16-24 gpm/ft^2 (40-60 m^3/hr/m^2).

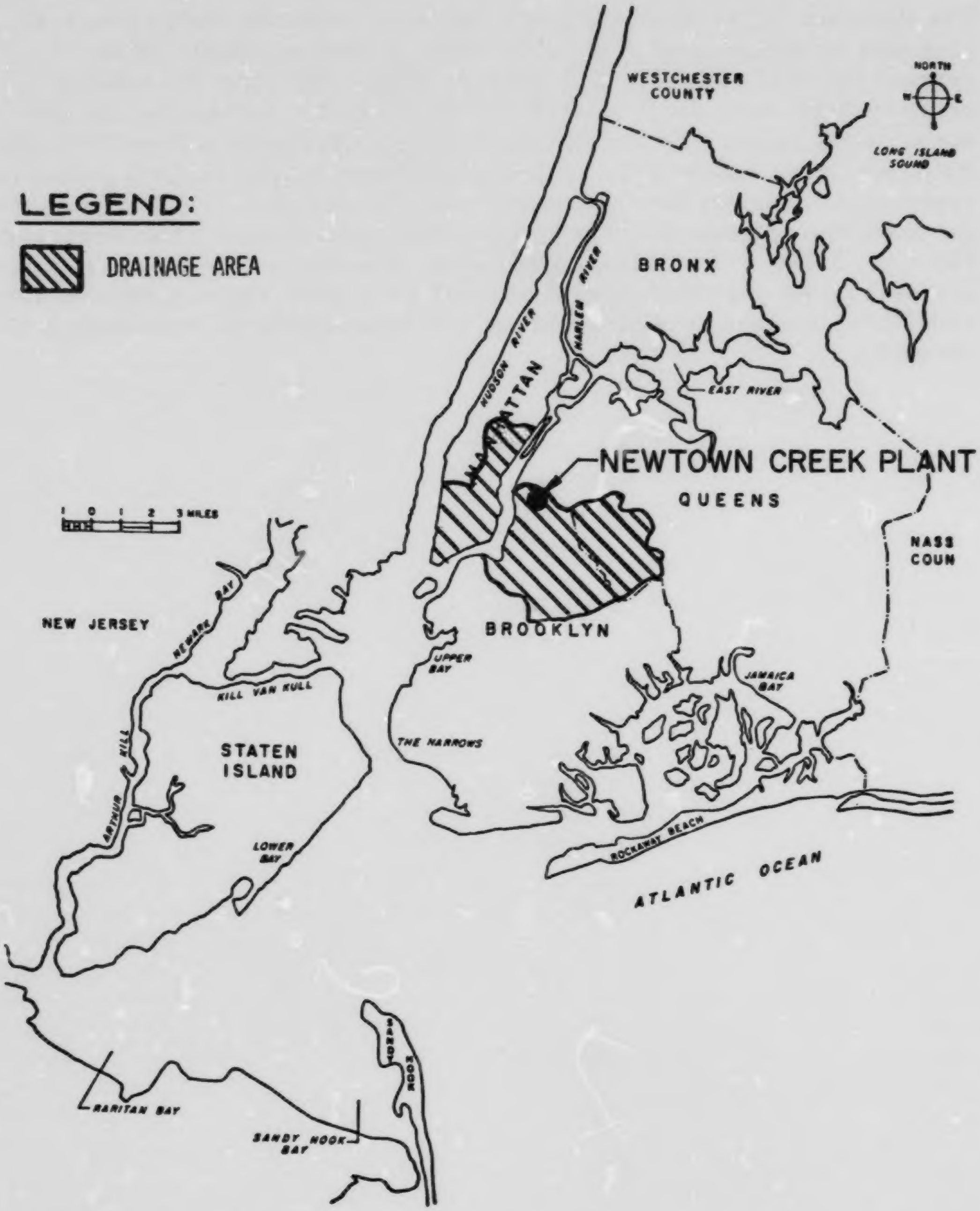
The most extensive CSO filtration testing program to date was performed in Cleveland during 1970-71 (6). Using 6-in. (15 cm) pressurized dual media filters operating in a flux range of 8-24 gpm/ft^2 (20-60 m^3/hr/m^2), the reported removals were 93-98 percent of SS using polymer, and 50-75 percent without chemicals.

SCOPE OF PROJECT

The purpose of the study was to evaluate the HRF process on CSO flows, and on raw dry-weather sewage flows (RDWS). The tests were performed on a 30-in. (76 cm) diameter filter column to reduce the sidewall effects which were experienced with the smaller columns at Cleveland (6) and thus to closely approximate operations of a full scale HRF plant.

The pilot plant was located at the Newtown Creek Water Pollution Control Plant in Brooklyn, New York. Construction began in June 1975, with field testing and data collection extending from October 1975 to July 1977. The pilot plant was mothballed both winters to protect the piping and mechanical equipment from freezing.

The Newtown Creek plant receives flow collected by combined sewer systems from parts of Brooklyn, Queens and Manhattan as shown on Figure 1. The drainage area covers 15,390 acres (6233 ha) serving more than 2 million people and the land use division is 54 percent (area) high-medium residential, 23 percent commercial-business district, 13 percent light-heavy industry and 10 percent parks - cemeteries. Concerning the relative contributions of dry-weather sewage flow (RDWS), the division is 50 percent residential, 37 percent commercial-business district and 13 percent industrial.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MANHATTAN
EAST RIVER
NEWTOWN CREEK PLANT
QUEENS
NASS COUN
BROOKLYN
NEW JERSEY
NEWARK BAY
KILL VAN KULL
UPPER BAY
JAMAICA BAY
THE NARROWS
STATEN ISLAND
ARTHUR KILL
LOWER BAY
ROCKAWAY BEACH
ATLANTIC OCEAN
RARITAN BAY
SANDY HOOK BAY
SANDY HOOK

FIGURE 1 - NEWTOWN CREEK WATER POLLUTION CONTROL PLANT DRAINAGE AREA

The Newtown Creek plant utilizes a high rate activated sludge process preceded by bar screening and grit removal, and was designed for 60 percent removal of BOD and 70 percent of SS. The plant provides no primary treatment; the flow passes from the grit chamber directly into the aeration basins. Of the 12 sewage treatment plants in New York City, Newtown Creek receives the highest daily flows and the largest industrial component. The dry weather capacity is 310 mgd (1,173,000 m^3/day) but the plant can provide effective grit removal and secondary treatment for 580 mgd (2,195,000 m^3/day) during rain. Diversion structures (regulator devices) in the combined sewers channel the excess storm generated flows or CSO into nearby receiving waters to prevent hydraulic overloading at the plant.

SECTION 2

CONCLUSIONS

FILTRATION RESULTS - CSO TREATMENT

1. HRF treatment of CSO at 16 gpm/ft^2 (40 m^3/hr/m^2) constant flux provided overall average SS removals of 61 percent across the filter and 66 percent across the system with an average influent SS concentration of 182 mg/l. Average SS removals for the three testing modes (no chemicals, polymer only, polymer and alum) and test ranges were:

CSO: SS REMOVALS

	Plant Influent (mg/l)	Filter Influent (mg/l)	Filter Effluent (mg/l)	Filter Removals (%)	System Removals (%)
No chemicals	175	150	67	55	62
Poly only	209	183	68	63	67
Poly & alum	152	143	47	67	69
Average (weighted)	182	161	62	61	66
Range	(99-311)	(94-266)	(30-87)	(48-75)	(51-79)

BOD removals from CSO averaged 32 percent across the filter and 41 percent across the system with an average influent BOD of 136 mg/l. The removals improved with chemical additions. Average BOD removals for the three testing modes and test ranges were:

CSO: BOD REMOVALS

	Plant Influent (mg/l)	Filter Influent (mg/l)	Filter Effluent (mg/l)	Filter Removals (%)	System Removals (%)
No chemicals	164	131	96	27	41
Poly only	143	129	84	35	41
Poly & alum	92	85	53	38	43
Average (weighted)	136	118	80	32	41
Range	(79-223)	(67-139)	(49-99)	(26-45)	(30-50)

COD removals from CSO averaged 42 percent across the filter and 47 percent across the system with an average influent of 302 mg/l. As with BOD, chemical additions improved removals. Average COD removals for the three testing modes and test ranges were:

CSO: COD REMOVALS

	Plant Influent (mg/l)	Filter Influent (mg/l)	Filter Effluent (mg/l)	Filter Removals (%)	System Removals (%)
No chemicals	332	285	193	32	42
Poly only	306	295	159	46	48
Poly & alum	260	242	120	50	54
Average (weighted)	302	278	160	42	47
Range	(223-384)	(190-385)	(98-251)	(23-56)	(33-57)

2. High molecular weight cationic polymers appeared to provide most improved solids removal during CSO testing. In the one test using 1.0 mg/l of polymer (Betz 1150), 68 percent filter removal of SS was obtained with a 266 mg/l filter influent. Two tests with 1-2 mg/l of the same polymer and 17-35 mg/l alum feed obtained an average 72 percent SS removal with an average 154 mg/l influent.

3. The percent removal of SS in the filtration is largely dependent upon the strength of influent flows.

The CSO data was grouped on a weekday/weekend basis; SS influent strengths were noticeably higher during weekday tests (attributable to the higher background industrial component on weekdays).

RELATIVE SS CONCENTRATIONS

	Number of Runs	Filter Influent (mg/l)	Filter Effluent (mg/l)	Removals (%)
Weekday	5	179	58	68
Weekend	4	135	66	51

From the data it is apparent that the variability in filter removals is due to the influent strengths, since the effluent concentrations are essentially the same.

FILTRATION RESULTS - RDWS TREATMENT

4. Treatment of RDWS at flux values of 8 and 12 gpm/ft^2 (20 and 30 m^3/hr/m^2) with an average influent SS concentration of 138 mg/l provided SS removals averaging 65 percent across the filter and 67 percent across the system. The average results and ranges for all 8 and 12 gpm/ft^2 flux tests were:

RDWS REMOVALS

Overall RDWS	Plant Influent* (mg/l)	Filter Influent (mg/l)	Filter Effluent (mg/l)	Filter Removals (%)	System Removals* (%)
SS					
Average	138	132	46	65	67
Range	(113-170)	(51-183)	(15-75)	(50-77)	(50-78)
BOD					
Average	170	152	98	36	42
Range	(130-215)	(55-230)	(25-165)	(12-64)	(27-67)
COD					
Average	348	290	194	33	44
Range	(320-425)	(170-340)	(80-305)	(20-53)	(33-47)

* Results based on extremely limited plant influent data.

In a continuous series of HRF tests on RDWS (interrupted only for backwashing) with four filter runs at 8gpm/ft^2 (20 m^3/hr/m^2) without chemical feed directly followed by ten runs at 12 gpm/ft^2 (30 m^3/hr/m^2) with 0.5 mg/1 polymer feed, both modes provided SS removals of 67 percent with average run lengths of 5.3 hrs. Both the BOD and COD removals improved with the polymer addition. Subsequent testing with alum in combination with polymer failed to improve removals at the 12 gpm/ft^2 (30 m^3/hr/m^2) flux. The average results of the continuous series of RDWS tests were:

Continuous Series RDWS	Filter Influent (mg/1)	Filter Effluent (mg/1)	Removals (%)
SS			
8 gpm/ft^2, no chemicals	129	42	67
12 gpm/ft^2, 0.5 mg/1 poly	125	41	67
BOD			
8 gpm/ft^2, no chemicals	225	157	30
12 gpm/ft^2, 0.5 mg/1 poly	140	86	39
COD			
8 gpm/ft^2, no chemicals	270	195	28
12 gpm/ft^2, 0.5 mg/1 poly	265	174	34

SUSPENDED SOLIDS CAPTURE RESULTS

5. A filtration system should be designed on the basis of total mass of SS captured per unit of filter area or media volume per run under restrictions of head loss requirements and breakthrough of solids. Breakthrough is indicated by a visible increase in effluent solids concentration over a desired value.

From the testing the following mass removals data were obtained at a flux of 16 gpm/ft^2 (40 m^3/hr/m^2) for CSO tests and flux values of 8 and 12 gpm/ft^2 (20 and 30 m^3/hr/m^2) for RDWS tests:

SS CAPTURE BY HRF

	CSO Tests		RDWS Tests	
Capture Parameter	Average	Range	Average	Range
lbs/ft^2/run	3.7	(1.7-9.4)	2.9	(1.5-5.2)
lbs/ft^2/hr	0.76	(0.36-1.45)	0.50	(0.21-0.76)
lbs/ft^3/run	0.54	(0.27-1.45)	0.45	(0.22-0.79)
lbs/ft^3/hr	0.11	(0.06-0.22)	0.07	(0.03-0.12)

BACKWASHING

6. The filter backwash concentrate composites of the CSO and RDWS tests had the following average charateristics:

BACKWASH CONCENTRATE CHARACTERISTICS

	SS (mg/1)			Filter Leaf Test
	Average	Range	SDI	(% dry solids)
CSO	2353	(770-4064)	2.8	35
RDWS	2215	(1030-3570)	2.9	34

The backwash concentrate appeared amenable to dewatering. Volumes of water used for backwashing were:

BACKWASH WATER VOLUMES

	Percent of Flow Filtered	
	Average	Range
CSO	6.0	(2.4-7.8)
RDWS	8.3	(5.2-12.5)

7. Complete fluidization of the filter media is necessary for effective filter backwashing. An air supply of greater than 5 scfm/ft^2 (1.5 m^3/min/m^2) is required for 2-4 minutes of media scrubbing. Backwash water feed appeared satisfactory at 35 gpm/ft^2 (87 m^3/hr/m^2) for 6-10 minutes of media flushing. Full-sized plants will utilize less due to the absence of all wall effects that hinder backwash.

PRETREATMENT

8. The cross-hatch mesh rotary screening device used (trade name "Discostrainer") proved effective in removing grit and fibrous solids from RDWS and CSO. The unit discharged sludge cakes of 12-18 percent solids content, treating influents with SS levels of 100-300 mg/1. Having such a relatively high solids content in the sludge cake alleviates the need for further dewatering prior to ultimate sludge disposal.

   During CSO testing, equipped with a 40 mesh (420 micron) screen the unit appeared to effect a fairly consistent 10 percent SS removal with an average influent of 190 mg/1; with a 70 mesh (210 micron) screen approximately 16 percent SS removals were obtained with an average influent of 171 mg/1.

   The Discostrainer sludge cakes appeared to contain high levels of heavy metals but insufficient data is available to draw conclusions. Mass balances are not possible since sludge cake volumes were not determined.

9. Applications of the HRF system to sewage with heavy loadings of fibrous solids should not use a slotted element screening device, since the fibers tend to pass longitudinally through the screen. A true mesh or cross-hatch screen is required to prevent early plugging of the filter.

ADDITIONAL FILTRATION RESULTS

10. Settleable solids were removed (97-100%) by HRF treatment. The overall average for CSO and RDWS tests were:

SETTLEABLE SOLIDS REMOVALS

	Filter Influent (ml/l)	Filter Effluent (ml/l)	Removals (%)
CSO	4.7	0.06	98.7
RDWS	3.1	0.0	100

11. No conclusions can be made on heavy metals removal from CSO by HRF treatment. There were no evident correlations between metals removal efficiency and SS removal, chemical dosing or influent metals concentration. The results showed significant variation.

12. HRF treatment was not effective in the removal of dissolved solids, filtrate BOD and filtrate COD.

DISINFECTION

13. HRF without disinfection did not appear to reduce bacterial concentration.

14. A disinfection unit with a well-baffled chlorine contact chamber provided adequate disinfection (to less than 200 fecal coliforms per 100 ml) of HRF effluent (treated RDWS) at contact time of 9 minutes and a sodium hypochlorite dosage of approximately 7 mg/l (as Cl_2).

FULL-SCALE CAPITAL COSTS

15. Estimated capital costs of dual-treatment filtration facilities for 25 to 200 mgd (94,600-757,000 m^3/day) capacity plants were: (Capital cost estimates are given based on a design filtration flux of 16 gpm/ft^2 (40 $m^3/hr/m^2$) and including equipment for alum and polymer addition).

SUMMARY OF TOTAL PROJECT COSTS

HRF Plant Capacity (mgd)	Total Capital Cost (ENR = 2520)
25	$ 2,731,000
50	4,362,000
100	8,111,000
200	13,981,000

FULL-SCALE ANNUAL COSTS

16. Total estimates annual costs for HRF plants of 25 through 200 mgd capacities were:

SUMMARY OF TOTAL ANNUAL COSTS*

HRF Plant Capacity (mgd)	Annual Cost (450 hr/yr) CSO Treatment Plant	Annual Cost (8760 hr/yr) Dual-Treatment Plant
25	$ 238,050	$ 396,450
50	382,350	600,100
100	693,200	1,053,600
200	1,175,900	1,794,050

*The annual costs are in the categories of separate CSO treatment plants operating only during the estimated 450 hours of CSO per year and dual-treatment plants operating 8760 hours per year (365 days including 450 hours of CSO filtration). The costs include amortization, operation and maintenance.

SECTION 3

RECOMMENDATIONS

1. HRF treatment should be evaluated on the basis of mass removals per square foot of effective surface area or per cubic foot of media volume as opposed to length of filter run since the total mass captured appears to be the major factor determining the length of filter runs.

2. The HRF system does not remove dissolved material. Analytical determinations of dissolved solids, filtrate BOD, filtrate COD and trace metals should be made on influent flows to determine their relative contributions to the total loadings. If the dissolved fraction is sizeable, the applicability of HRF may be limited for dissolved material.

3. The current testing was performed on RDWS and CSO separately; it appears desirable to evaluate the HRF system in an actual dual treatment capacity going directly from RDWS to CSO treatment.

4. Both the 1971 Cleveland (EPA report no. 11023 EYI 04/72) and the present New York City studies were performed at sewage treatment plants with significant industrial components in the flows. Further testing should be performed on sewage from predominantly domestic areas which have a smaller component of dissolved organic solids.

5. Efforts should be directed toward the development of mathematical relationships for simulation of the HRF process to mathematically evaluate filter performance under varying SS concentrations and other appropriate parameters.

6. On-site and drainage area rainfall and flowrates should be established for accurately timed startups and for more efficient operation in CSO treatment.

7. Large fluctuations in pressure head appear to cause solids shearing in the filter media resulting in breakthrough of solids to the effluent of the pilot plant; therefore maintenance of a regulated hydraulic head should be provided in full-scale facilities.

8. A full-scale HRF installation of at least 25 mgd (94,600 m^3/day) capacity should be engineered and constructed to demonstrate the capabilities for dual-treatment of RDWS and CSO.

9. To provide additional process and design data on the HRF system, further testing programs should include data collection in the following areas:

    a. Cost optimization of chemical additives (e.g., backwashing with polymers to precoat the filter media and provide more efficient sludge handling; heavy chemical feed rates during the onset of filtration for rapid precoat formation to possibly eliminate the need for continuous chemical feeding) to the filter.

    b. Effective mixing techniques to provide maximum benefits from chemical coagulant additives.

    c. Effective backwashing procedures.

    d. Backwash sludge handling and disposal, evaluating both dewatering techniques and methods of ultimate disposal.

    e. Declining rate filtration with a pilot plant specifically engineered for this purpose, i.e., to insure maintenance of a constant hydraulic head on the filter.

    f. Utilization of the Discostrainer to concentrate backwash water.

    g. Other areas of potential HRF application (e.g., effluent polishing, treatment of urban runoff).

    h. Chlorination of CSO for preventing growths on the HRF media, extending media life and establishing effective disinfection procedures.

SECTION 4

PILOT PLANT FACILITIES

GENERAL DESCRIPTION

The pilot plant was set up at the Newtown Creek plant's No. 8 grit chamber (see Figure 2). The influent sewage was pumped from a channel situated after the plant's bar screens but before the grit chambers and passed through a rotary screen (for grit and coarse solids removal) and then pumped onto the dual media high rate gravity filter. The filter effluent was discharged to the plant drain. Two storage tanks, installed between the rotating screen and filter, were used during the shorter storm flow conditions to extend filter runs with retained CSO. The same influent source and process flow routing were used for treating both CSO and RDWS. All equipment was located outdoors, exposed to the weather. A process schematic of the pilot plant is given in Figure 3. Figures 4 and 5 show photographs of the facilities.

The HRF column was fabricated from transparent lucite plastic to permit observation of the filtration process (Figure 6). The filter media was 48 in. (122 cm) and later 60 in. (152 cm) of No. 3 anthracite over 30 in. (76 cm) of No. 612 sand. The column was designed to simulate a full size filter in both filtration operation and backwashing for the treatment of CSO and RDWS. The filter bottom was of the same type as used in the Cleveland study, i.e., a solid disc containing tubular nozzles spaced to allow an even flow distribution. Two 6-in. (15 cm) diameter acrylic columns were installed for supplementary testing at various flux values and coagulant feeds. Two chemical feeding systems were used for polymer and other chemical additions. An in-line static mixer was installed late in the project in the filter influent line just after the chemical feed connections. A disinfection contact chamber was available to receive a sidestream of the pilot plant filter effluent for disinfection with sodium hypochlorite.

The flow through each filtration column was controlled by flow meter observation and manual regulation of valves on each filter effluent pipe. Pressure gauges were located along the height of the columns to profile head losses throughout the filter depth. Backwash water was obtained from a city water hydrant; an air gap was provided between the hydrant

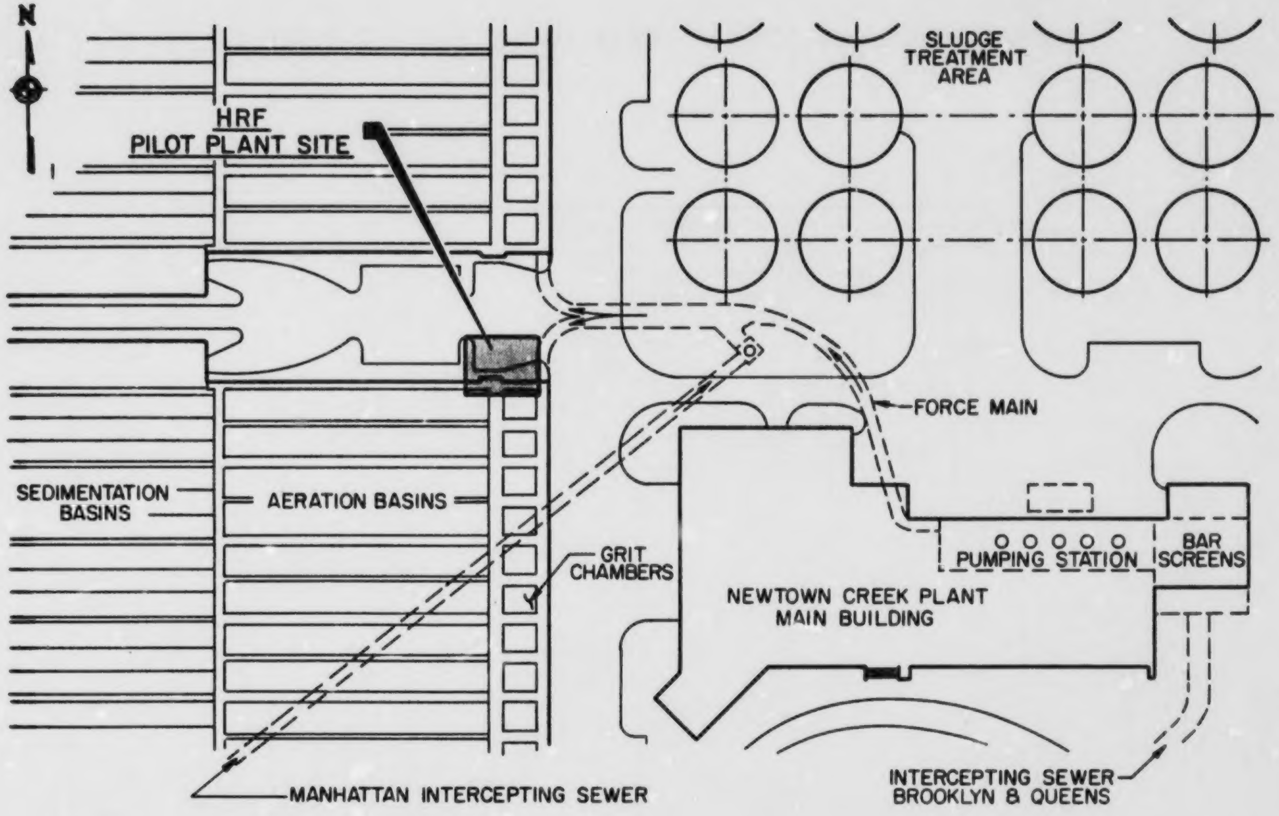

N
HRF
PILOT PLANT SITE
SLUDGE
TREATMENT
AREA
FORCE MAIN
SEDIMENTATION
BASINS
AERATION BASINS
GRIT
CHAMBERS
PUMPING STATION
BAR
SCREENS
NEWTOWN CREEK PLANT
MAIN BUILDING
MANHATTAN INTERCEPTING SEWER
INTERCEPTING SEWER
BROOKLYN & QUEENS

FIGURE 2 - HRF PILOT PLANT LOCATION

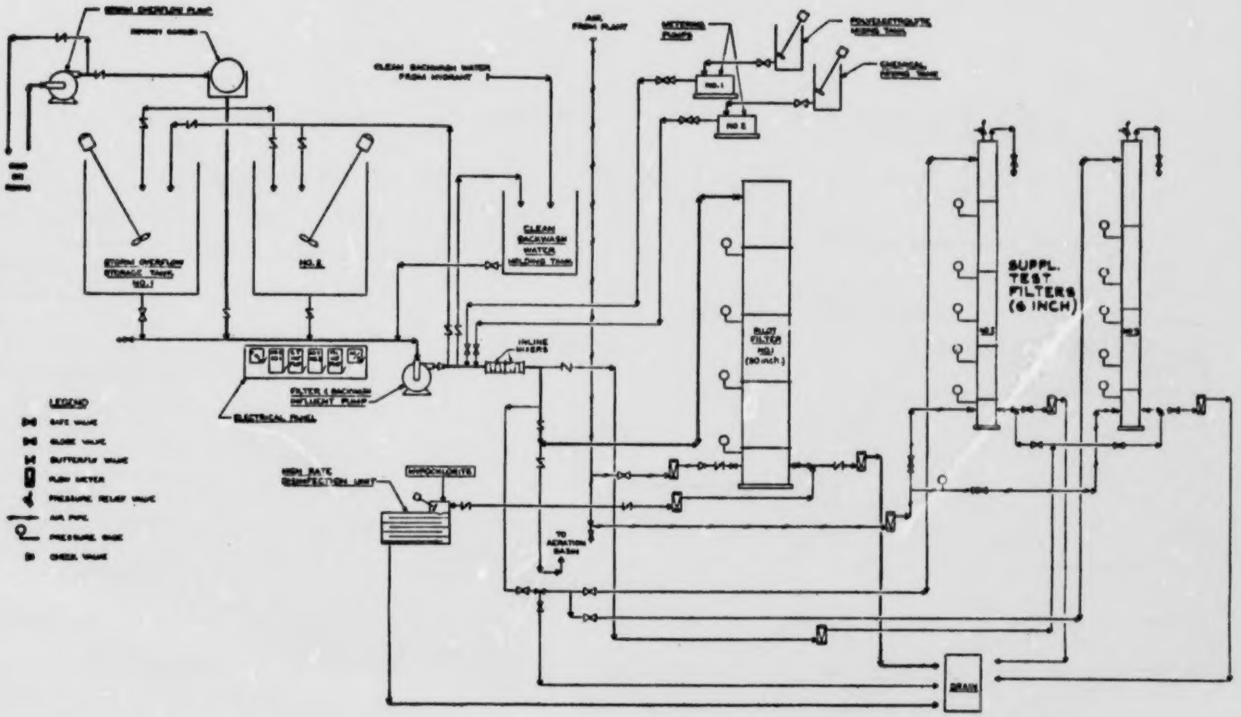
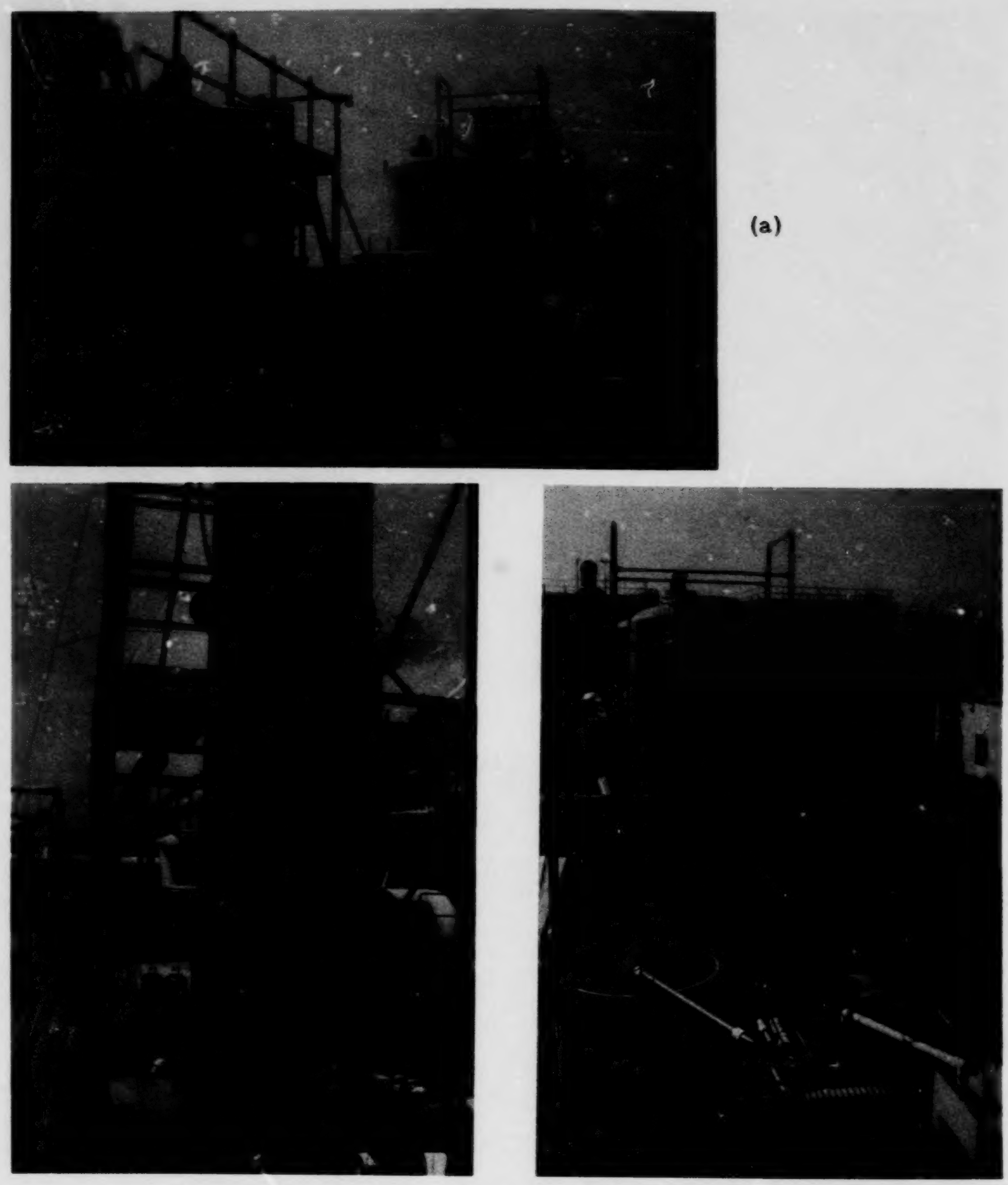

STORM OVERFLOW PUMP
AIR FROM PLANT
CLEAN BACKWASH WATER FROM HYDRANT
METERING PUMPS
NO. 1
NO. 2
POLYELECTROLYTE MIXING TANK
CHEMICAL MIXING TANK
STORM OVERFLOW STORAGE TANK NO. 1
NO. 2
CLEAN BACKWASH WATER HOLDING TANK
INLINE MIXERS
FILTER & BACKWASH INFLUENT PUMP
ELECTRICAL PANEL
PILOT FILTER NO. 1 (30 inch)
SUPPL. TEST FILTERS (6 INCH)
NO. 2
NO. 3
HIGH RATE DISINFECTION UNIT
HYPOCHLORITE
TO AERATION BASIN
DRAIN
LEGEND
GATE VALVE
GLOBE VALVE
BUTTERFLY VALVE
FLOW METER
PRESSURE RELIEF VALVE
AIR PIPE
PRESSURE GAGE
CHECK VALVE

FIGURE 3 - HRF PILOT PLANT - PROCESS FLOW DIAGRAM

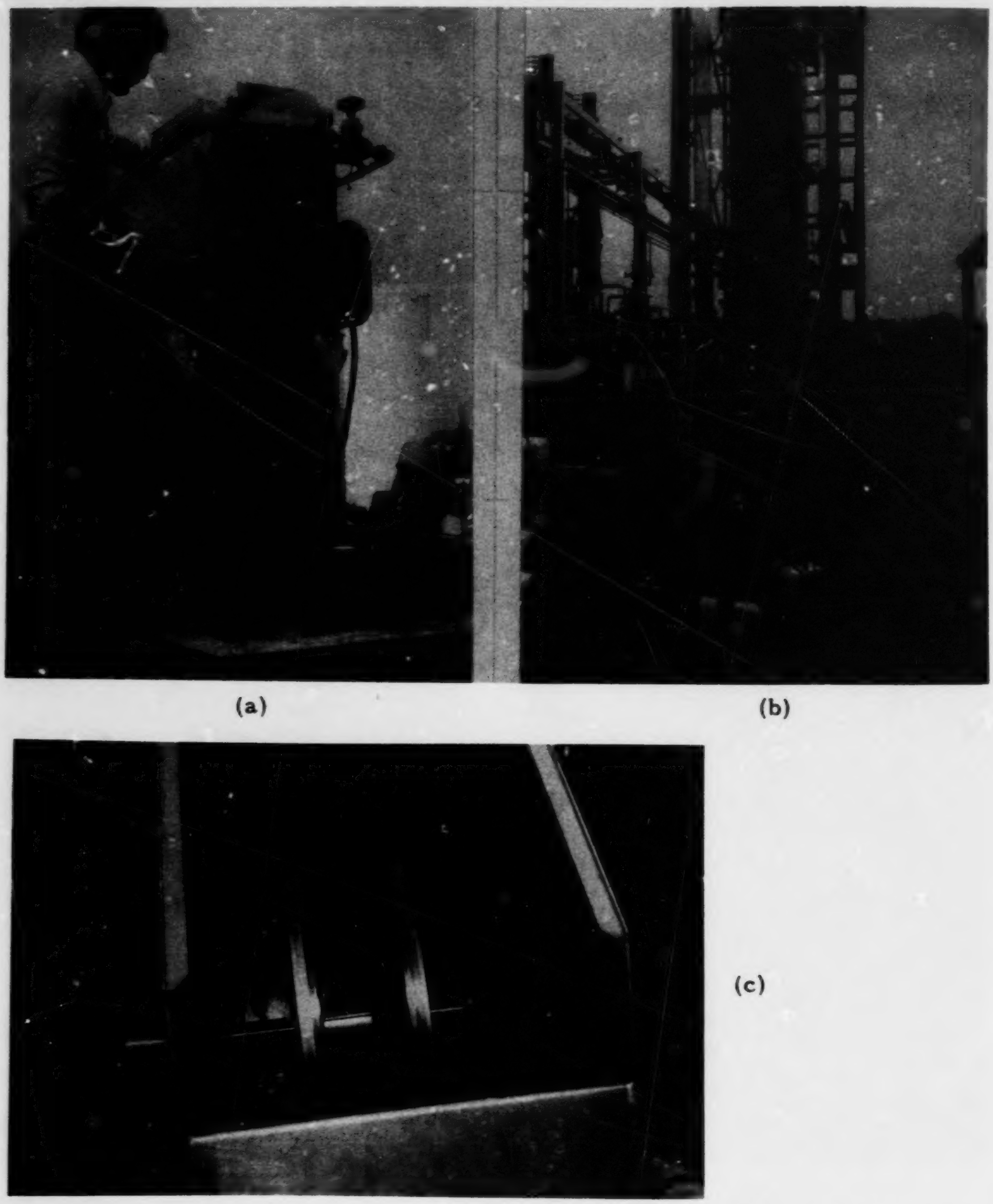


(a)

(b)

(c)

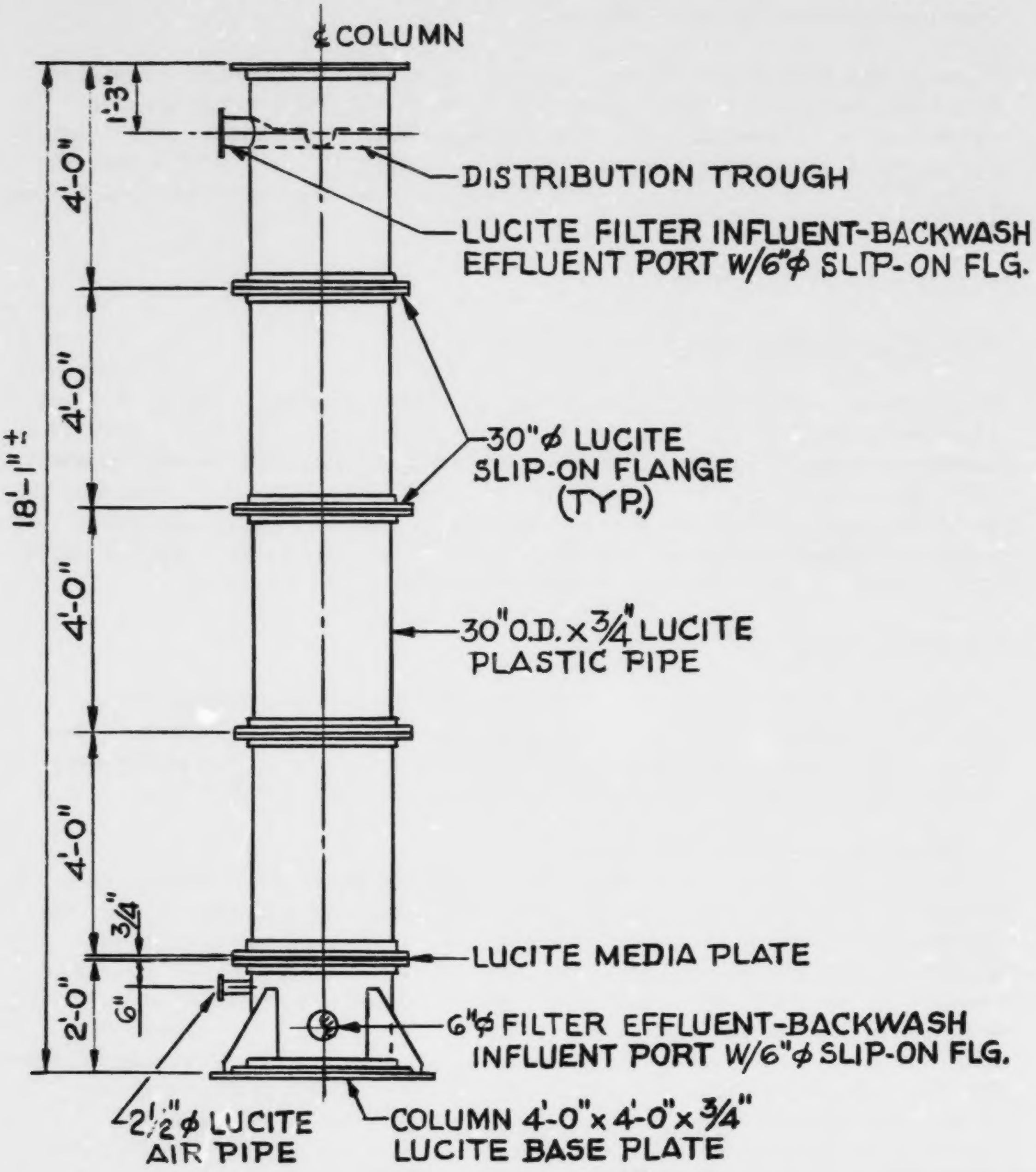
Figure 4. HRF pilot plant facilities. (a) Storage tanks and filter columns during testing. (b) Lower section of 30 in. column; influent and effluent samples. (c) 30 in. column operation and water sampling; disinfection chamber in center foreground.


(a)

(b)

(c)

Figure 5. HRF pilot plant facilities. (a) Discostrainer showing effluent pipe and sludge discharge. (b) 30 in. and two 6 in. filter columns with 30 in. column effluent pipe in foreground. (c) Discostrainer interior while in operation.



℄ COLUMN
1'-3"
4'-0"
4'-0"
4'-0"
4'-0"
3/4"
6"
2'-0"
18'-1" ±
DISTRIBUTION TROUGH
LUCITE FILTER INFLUENT-BACKWASH EFFLUENT PORT W/6"φ SLIP-ON FLG.
30"φ LUCITE SLIP-ON FLANGE (TYP.)
30" O.D. x 3/4" LUCITE PLASTIC PIPE
LUCITE MEDIA PLATE
6"φ FILTER EFFLUENT-BACKWASH INFLUENT PORT W/6"φ SLIP-ON FLG.
2 1/2"φ LUCITE AIR PIPE
COLUMN 4'-0" x 4'-0" x 3/4" LUCITE BASE PLATE

FIGURE 6 - HIGH RATE FILTER COLUMN

and the filters to prevent contamination. Backwash air was fed from the Newtown Creek plant's air system.

Upon completion of each filter run, valves were readjusted to allow the filter influent pump to send clean (city) water upward through the filter column for a backwash cycle. During backwashing the media was fluidized and agitated with low pressure air at 45 psi (3.2 kg/cm^2) with a flux of 5 cfm/ft^2 (1.5 m^3/min/m^2). The backwash flow was conveyed directly into an adjacent plant aeration tank.

PILOT PLANT EQUIPMENT

Pilot Plant Influent Pump

The pilot plant influent pump is a self-priming centrifugal pump, Barnes Manufacturing Company, model 105-Cue-E with cast iron body, open type impeller, 6 in. (15 cm) suction and discharge. The pump was driven by an 1175 rpm, 10 hp (7.5 kW) TEFC motor, operating at 230/460 volts and the pumping capacity was rated at 500 gpm (32 l/s). The pump and motor were mounted integrally on a base plate located directly over the influent wastewater channel and about 3 ft (0.9 m) above the water surface.

Rotary Screens

Two screening units were successively tested, both continuous duty, gravity flow, self-cleaning systems manufacturer by Hycor Corp. The units were located atop the CSO storage tanks 10 ft (3 m) above the level of the influent source and 12 ft (3.7 m) above ground level.

Rotating Slotted Drum Screen --

This unit, identified by the trade name Rotostrainer, used during the early stages of testing, had a cylindrical slotted straining element rotating on its horizontal axis and accepting incoming wastewater on its outside surface. The slotted cylinder was constructed of wedgeshaped stainless steel wire oriented with the line of revolution and supported by cross rods. Interchangeable cylinders were provided, with either 250 micron, 500 micron, or 750 micron openings between the wires. The straining surface for the model RSB-2510 Rotostrainer was 25 in. (63 cm) diameter and 10 in. (25 cm) wide. A soft metal doctor blade, in contact with the rotating surface, removed the trapped debris. The strained wastewater passed through the cylinder to a drainage line.

Rotating Mesh Disc Screen (Figure 7)--

This second unit, identified by the trade name Discostrainer, was supplied after disuse of the Rotostrainer. It consisted of two vertical disc screens rotating in parallel against a water-tight seal while partially submerged in a box chassis. The wastewater entered between the disc screens at one end and flowed radially through them to the receiving chambers at either side. The screens were washed with recirculated screened effluent by a jet spray directed on the outer surface of the screens at the end opposite the influent. The trapped solids collected at this end were gradually lifted over an adjustable weir into a collection box. The discs for the model DS-110 Discostrainer were aligned 7 in. (18 cm) apart and had a diameter of 39 in. (100 cm), and were supported by a stainless steel axle, spokes and rim. The interchangeable discs had true cross hatch stainless steel wire screens, and 420 micron (40 mesh) and 210 micron (70 mesh) screen opening sizes were evaluated in the testing program.

Filter and Backwash Influent Pump

This horizontal centrifugal pump, manufactured by Gorman-Rupp Industries, Model 14A2B-4 with cast iron body and open type impeller, 4-in. (10 cm) suction and discharge. The pump was driven by a 1740 rpm, 7.5 hp (5.6 kW) TEFC motor operating at 230/460 volts and the pumping capacity was rated at 200 gpm (13 l/s). The pump and motor were mounted integrally on a base plate located at ground level between the rotary screen and pilot filter columns.

Filter Columns

Pilot Filter Column (Figure 6)--
This column was of 0.75 in. (1.9 cm) thick lucite plastic molded into a 30 in. (76 cm) diameter (o.d.) open top tube. The filter cross section area was 4.5 ft^2 (0.42 m^2). The column was 18 ft (5.5 m) high, consisting of four 4-ft (122 cm) sections over a 2 ft (61 cm) base section, all connected by bolted flanges. The column was guaranteed by the manufacturer to sustain 75 psig (5.3 kg/cm^{2}g) internal pressure. The filter media was supported by a lucite bottom plate containing multiple lucite nozzles. Above the plate, an 18 in. (45 cm) gravel layer was provided to support the anthracite-sand media and prevent media loss through the nozzles. Four pressure gages were spaced along the column depth to measure head loss from the overlying water through the anthracite, sand and the filter bottom. An impact rotameter and butterfly valve were installed on the filter discharge pipe for measuring and controlling the rate of flow.

Supplementary Testing Filter Columns--
Two columns, each 6 in. (15 cm) diameter, were made of transparent acrylic tubing in four sections with a total height of 16 ft (4.9 m). A top plate with air and water relief valves allowed the filters to be pressurized up to 30 psig (2.1 kg/cm^{2}g). The filtration flux was controlled by an indicating rotameter and globe valve on the effluent pipes of each filter.

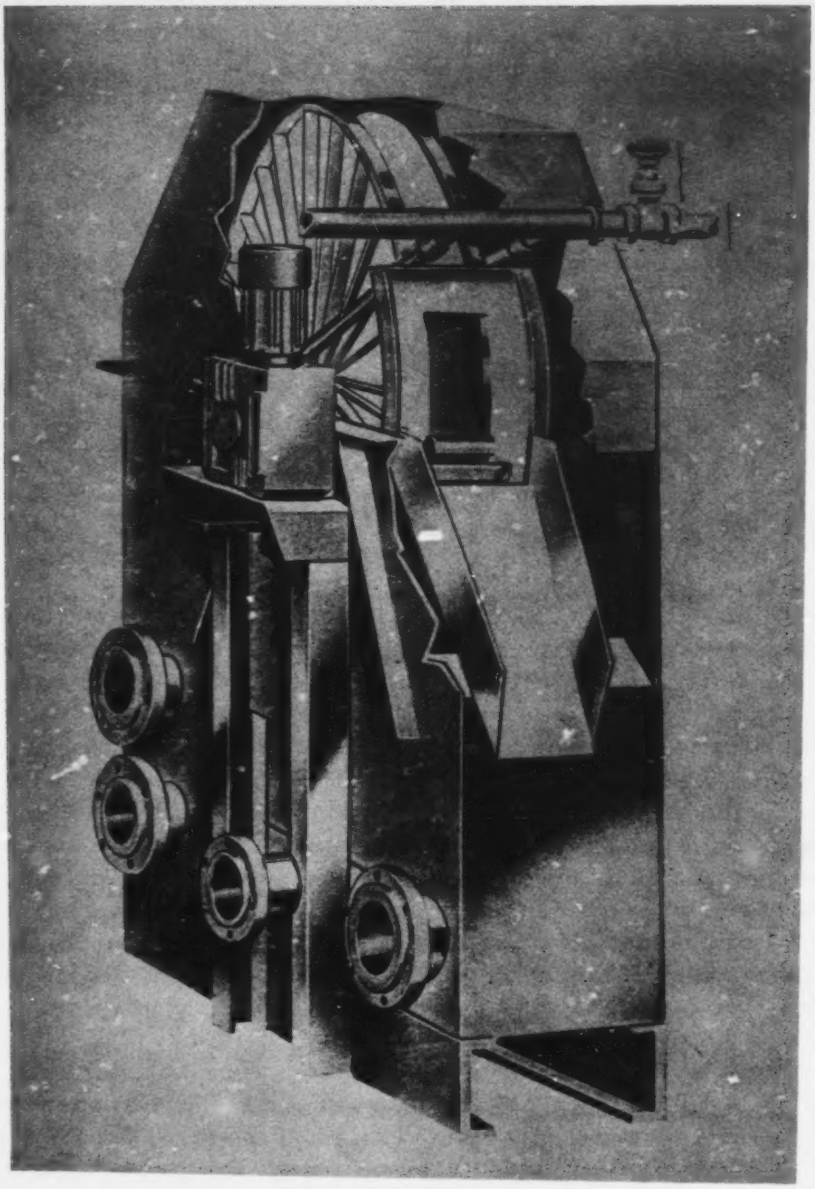


FIGURE 7 - DISCOSTRAINER MODEL DS-110

Chemical Feed Systems

Both systems consisted of a polyethylene 40 gal. (150 l) chemical solution tank, a diaphragm metering pump with 0.25 hp (0.19 kW) motor, and a separate input line to each filter. A portable Lightnin mechanical mixer was employed for solution preparation. Two in-line static mixing units were installed in series in the influent line to the filters just after the chemical inputs. Each in-line mixer consisted of a 36-in. (91 cm) section of PVC pipe, with flanged ends, containing stationary PVC helical vanes along its length. The in-line mixers were supplied by Kenics Corp. and the metering pumps were manufactured by Wallace and Tiernan, Inc.

Storage Tanks

Combined Sewer Overflow Storage Tanks --

Two tanks were provided for filter influent storage. One tank was of carbon steel plate with a 5,000 gal. (19 m^3) storage capacity; the other tank was of fiberglass with a 8,000 gal. (30 m^3) capacity. Each tank was equipped with a mixer for preventing solids settlement during storage. Each mixer was equipped with dual propellers and was driven by a 3 hp (2.2 kW) totally enclosed motor which was integrally mounted on a gear reduction unit providing a shaft speed of 350 rpm. The mixer was manufactured by Lighnin Mixing Equipment Company. The two tanks provided approximately 2.5 hrs wastewater supply to the filter at 16 gpm/ft^2 (40 $m^3/hr/m^2$).

Backwash Water Tank --

An open carbon steel tank of 1,000 gal. (3.8 m^3) capacity was used for holding potable city water for filter backwashing.

Piping and Valves

All piping and connections between equipment were of Schedule 40 PVC. All flow control valves (butterfly, gate and globe types) were of cast iron.

Disinfection Unit

This was of carbon steel plate and consisted of a contact chamber 4 ft x 2 ft x 18 in. (122 cm x 61 cm x 46 cm) high, fitted with panels (baffles) of corrugated fiberglass spaced 1.5 in. (3.8 cm) apart to provide a serpentine path for the disinfected filter effluent. A seven gal. (25 l) mixing chamber was separated from the contact chamber by a V-notch weir. Sodium hypochlorite solution was metered into the mixing chamber and rapidly mixed by a 0.05 hp (0.037 kW) portable mechanical mixer. At a flow rate of 10 gpm (0.63 l/s) the approximate detention times were 40 seconds for rapid mixing and 8 min for chlorine contact. The resulting mean velocity gradient, G, within the rapid mixing chamber is 1050 sec^{-1} or, combined with detention time (Gtd), is 42,000. The baffled contact chamber, with a reported head loss of 1.5 in. (3.7 cm) (7), had values of G and Gtd of 25 sec^{-1} and 12,000, respectively.

SECTION 5

TESTING PROGRAM

OBJECTIVES

The testing program had three basic objectives:

1. Extend the results of the Cleveland program (6) demonstrating the technological advantage and treatment performance of HRF in treating combined sewer overflows.

2. Determine the feasibility of an HRF system for dual functions, treating both CSO and RDWS.

3. Establish treatment design parameters for application in full scale filtration facilities.

Evaluation of the filtration process, the heart of the HRF system, was the focus of the study. The screening devices (the Rotostrainer and Discostrainer) were not evaluated towards optimization but were used only to provide reasonably effective pretreatment for extending filter operation periods.

LABORATORY ANALYSES

The principal laboratory analyses performed for the study were: total suspended solids (SS), five-day biochemical oxygen demand (BOD) and chemical oxygen demand (COD). These and other analyses were performed on the influent, effluent and backwash effluent to provide more detailed information on process performance. Table 1 is a list of all analyses performed and the procedures utilized. All analyses were performed by the NYC Industrial Wastes Control Laboratory at the Newtown Creek Water Pollution Control Plant within 24 hours after each test. Trace metals were analyzed later after preservation by acidification and freezing.

The major parameter for determining filtration effectiveness was SS,

TABLE 1. LABORATORY ANALYSES

Analysis	Method Used
Solids	
Suspended Solids (SS)	Filtered through glass fiber filter (Whatman GF/C) and dried at 103-105°C.
Volatile Suspended Solids (VSS)	Filtered and ignited at 550°C.
Settleable Solids (Set. S.)	Imhoff cone, by ml/l.
Organic	
Biochemical Oxygen Demand (BOD)	Unblended, diluted and incubated for 5 days at 20°C.
Chemical Oxygen Demand (COD)	Oxidized by $K_2Cr_2O_7$ solution.
Filtrate Biochemical Oxygen Demand (FBOD)	Filtered through Whatman No. 1 paper, diluted and incubated for 5 days at 20°C.
Ultimate Biochemical Oxygen Demand (UBOD)	Unblended, diluted and incubated for 20 days at 20°C.
Filtrate Chemical Oxygen Demand (FCOD)	Filtered through Whatman No. 1 paper and oxidized by $K_2Cr_2O_7$ solution.
Trace Metals	
Cadmium, Chromium, Copper, Lead, Nickel, Zinc	Acidification, conventional atomic absorption
Mercury	Acidification, cold vapor atomic absorption
Bacteriological	
Total Coliforms	Multiple dilution
Fecal Coliforms	Membrane filter (pore size 0.45 micron)
Special Sludge Tests	
Gravity Thickening	Sludge volume index (modified)
Dewaterability	Buchner filtration vs time; Filter leaf test.

since the system is essentially a solids removal process. Insoluble BOD, COD and trace metals are also removed to some degree by the filters. Phosphate removal by the HRF system was not determined due to the low levels found in the Newtown Creek plant influent. The statewide limit on phosphate content in detergents has greatly reduce phosphorus concentrations in all New York City plant influents.

PROGRAM SCOPE

The testing program consisted of two separate phases. Phase I involved filter testing of CSO for a minimum of 10 separate rainstorms over the spring, summer and fall seasons. Phase II involved the continuous filter testing of RDWS over a minimum seven day period of no precipitation, the testing was performed 24 hours per day with interruptions only for filter backwashing. The 30-in. (76 cm) HRF column was utilized in all CSO and RDWS testing and in all testing for establishment of full-scale treatment design parameters.

Selection of rotary screen mesh size, filter media, types of polymer and coagulant were based on the results of the previous HRF testing at Cleveland (6). The 6-in. (15 cm) filter columns were utilized only to establish flux values and chemical feeds for the primary tests with the large column.

PILOT PLANT

Screening

The Cleveland testing concluded that a 40 mesh (420 micron) screen aperture was satisfactory when utilized in conjunction with dual media high rate filters. Accordingly, the Rotostrainer was used with either of two slotted cylinders having openings equivalent to 35 mesh (500 microns) and 60 mesh (250 microns). The Discostrainer unit was equipped with 40 mesh (420 micron) and 70 mesh (210 micron) screen sizes.

Media

The filter media used was the same as that found satisfactory in Cleveland (6) - anthracite over sand - with the following specifications:

Material	Effective Size	Uniformity Coefficient	Depth
No. 3 Anthracite	3.85 mm	1.52	48 or 60 in. (122 or 152 cm)
No. 612 Sand	2.0 mm	1.32	30 in. (76 cm)

Chemicals

Chemical filtration aids included alum and several types of organic polyelectrolyes, equivalent to those found satisfactory during previous CSO treatment studies (6, 7, 8).

Polymer	Type	Manufacturer
Purifloc A-23	Anionic	Dow Chemical Co.
Hercofloc 1054	Anionic	Hercules Inc.
Zetag 92	Cationic	Allied Colloids Ltd, Engld.
Betz 1150	Cationic	Betz Laboratories
Magnifloc 561C	Cationic	American Cyanamid Co.
WT 2575	Cationic (liquid)	Calgon Co.

CSO TESTING

The pilot plant was to be activated for testing when storm runoff increased the flow to the Newtown Creek plant above the normal dry weather flow. A minimum of 24 hr of antecedent dry weather were considered necessary for a valid CSO test to allow deposition in the collector systems. CSO was to be tested at any time of the day and, later in the project, any time of the night. Filtration testing was conducted without chemical additions, with polymer alone, or with polymer and alum in combination.

During filter operation, observations were made on the filter flux and on gauge pressures along the depth of the filter column. Grab samples were taken of the plant influent (Pi) ahead of the rotary screen and before the plant grit chambers, filter influent (Fi) after the screen, and of filter effluent (Fe). The observations and samples were taken and laboratory analyses performed according to the schedule given on Table 2.

Following the same schedule as the grab samples, composite samples were taken of Pi, Fi and Fe and analyzed for SS, VSS, BOD, FBOD, COD, FCOD, UBOD, Set. S. and trace metals.

The majority of the tests were conducted at a constant filtration rate. Filtration was ended when the rate decreased by at least 50 percent (this usually occurred suddenly within the last half hour of testing) or when the filter effluent was of visually poor quality, indicating solids breakthrough in the filter. However, two runs employed a declining filtration rate in which the flux was not regulated by adjusting the effluent valve but was allowed to decline under a constant, regulated head.

TABLE 2. CSO SAMPLING AND ANALYTICAL SCHEDULE

Time After Start of Filter Operation (Minutes)		Analyses			
* 0	Observations	SS	BOD	FBOD	COD
15	"	SS	BOD	FBOD	COD
30	"	SS	BOD	FBOD	COD
60	"	SS	BOD	FBOD	COD
90	"	SS			
120	"	SS	BOD		COD
150	"	SS			
180	"	SS			
210	"	SS			
240	"	SS	BOD	FBOD	COD
270	"	SS			
300	"	SS			
330	"	SS	BOD		COD
360	"	SS			
390	"	SS			
420	"	SS			
450	"	SS			
480	"	SS	BOD		COD

* The 0 minute samples were taken about 2 minutes after the start of filtration to allow flushing of water remaining in column.

BACKWASHING PROCEDURES

During filter backwash cycles attempts were made to determine the most effective operational procedure, minimizing the volume of backwash water necessary for filter cleaning. In general, volumes of low pressure air, 5 cfm/ft^2 (1.5 m^3/min/m^2) at 45 psi (3.2 kg/cm^2) were used to scrub the media and loosen trapped solids early in the cycle. A low rate, 8-15 gpm/ft^2 (20-37 m^3/hr/m^2) of water, fed with the air or in sequence with air would aid in the scrubbing process. The air feed was stopped before the backwash fluid reached the level of the discharge pipe, and water alone was fed at a high rate, 22-35 gpm/ft^2 (54-87 m^3/hr/m^2) until the media was flushed clean, with a distinct separation of the anthracite and sand layers.

Samples of the backwash effluent were collected at the point where the effluent discharged into an aeration basin of the Newtown Creek Plant. Samples were taken at maximum 30-second intervals throughout the duration of dirty backwash discharge. Both composite and grab sampling methods were used to estimate the total amount of material trapped on the filter during each run and to profile backwash solids concentration with time. Analyses of SS were made on all backwash samples, and the composites were also tested for VSS, BOD, COD, Set. S., trace metals, gravity thickening and dewaterability.

The Discostrainer had a continuous backwashing system incorporated into the unit. The sludge from the strainer was sampled and analyzed for trace metals and dry solids content.

RDWS FILTER TESTING

This phase of the testing program utilized the same operating procedures as the CSO testing. Due to the concern for achieving seven consecutive dry-weather days for filter testing, as required under the project work plan, the RDWS phase of the sampling program was scheduled to be completed first in the project.

During RDWS testing, the plant influent, filter influent and filter effluent were sampled at hourly intervals and analyzed for SS, BOD and COD. FBOD analyses were also performed on samples taken every second hour. Composite aliquots were taken with each sample and analyzed upon completion of each filter run as was done under CSO testing. Each filtration test proceeded until the head loss reached 5-7 psi (0.35-0.50 kg/cm^2) (bottom gauge pressure 0) or until a solids breakthrough occurred. The filter was then backwashed and a new filter run begun. Testing occurred 24 hours per day over a 9-day period. Various flux and chemical feeds were evaluated during this period.

ADDITIONAL TESTING

Metals

The 6-in. filter columns were utilized for special metals removal tests early in the program to determine the extent of the precipitation and coagulation of metals in the filter. In parallel operation, one filter received influent flow adjusted to pH 8.5 with lime addition and polymer, the other filter received flow with only polymer addition. The sampling followed the same procedures as in CSO testing. Analyses were performed for copper, chromium, cadmium, zinc, nickel, lead and mercury.

Bacteriological

Bacteriological testing was conducted to evaluate bacterial removals by filtration and to evaluate the disinfection unit.

The filter testing involved sampling of plant influent and effluent during selected RDWS and CSO tests. Analyses were performed for total and fecal coliforms to provide estimates of removals across the HRF system.

The disinfection testing was performed during selected HRF tests by diverting a 10 gpm (0.63 l/s) sidestream of filter effluent to the disinfection unit. A controlled gravity feed of 12 percent sodium hypochlorite solution entered the influent chamber and was mechanically mixed with the filter sidestream before passing into the corrugated baffle contact chamber. Dosages equivalent to 5, 10, 15 and 30 mg/l chlorine were added in succession, with each dosage period lasting about 15 min. After an initial 10 min. for solution equilibrium, samples of contact chamber effluent were taken at the 10 and 15 min. points. An influent sample (filter effluent) was taken at the 10 min. point of each dosage period.

Concurrent with each dosage period the chlorine residual was measured with a visual chlorine comparator. Residual chlorine in the contact chamber effluent samples was eliminated by sodium thiosulfate crystals present in the sterilized sample bottles. The influent and effluent samples were analyzed for fecal coliforms immediately after the disinfection testing period, utilizing the membrane filter technique.

SECTION 6

TESTING RESULTS

OPERATIONAL EXPERIENCE

The test period extended from October 1975 through June 1977. HRF pilot plant evaluations were performed on 18 storm generated CSO and on 29 filter runs with RDWS. The complete data file can be found in the appendix.

Since filter operation generally was effective for 4 to 10 hours before backwashing was required, relatively few CSO events lasted long enough to adequately evaluate CSO treatment. This, coupled with the uncooperative weather patterns of 1976-1977, mechanical breakdowns and the misapplication of the original screening unit ahead of the filter, all contributed to the project's rather lengthy test period.

During the first few weeks of testing, the Rotostrainer was used for screening with retention of the screened flows in the storage tanks. The retained flows were kept well mixed and then pumped to the filter columns. Twenty-four tests on RDWS were performed during nine consecutive days in October 1975 (tests D1-24). The results are discussed later in this section under RDWS testing. Three CSO events (S1-3) were then tested in November 1975, but experienced poor filter performance, excessive head loss and filter blinding within 0.5 to 2 hours. The blinding appeared to be caused by a mat of slimy and fibrous material which formed on the surface and within the first few inches of the filter media. When this layer was pierced, the filter was able to accept flow normally. This problem did not occur during the continuous RDWS testing.

Because of the operating conditions of the pilot plant, after the RDWS tests and between storm tests, some sediment and water (4-6 in. after draining) remained in the bottom of the storage tanks in a light-deficient environment ideal for slime propagation. This material, in combination with the normally heavy fiber load to the Newtown Creek plant and the heavier sediment load received during the first flush portions of storm flow, may have encouraged the rapid formation of a relatively impervious mat on the filter soon after the screened CSO was pumped from the storage tanks. The filter blinding was apparently caused by these operating conditions of the pilot plant and would not occur in full-scale HRF facilities where open storage tanks, if any, would be used.

To prevent a recurrence of the problem, thereafter the storage tanks were thoroughly flushed and the filters and tanks were chlorinated after each complete CSO test. This procedure worked well in controlling the slime; however, while the duration of subsequent filter operations increased to a degree, fiber matting continued to be a problem. It later became evident that the slime problem had masked the ineffectiveness of the Rotostrainer in both solids and fiber removal.

In July 1976 a test was made with a 40 mesh screen (two-directional mesh) placed at the Rotostrainer effluent pipe to trap any coarse solids which may have passed through the 60 mesh slotted (unidirectional) drum. The 40 mesh screen clogged completely in less than a minute, showing that the slotted strainer is not suited for treating sewage with high concentrations of fibrous material since the fibers tend to pass longitudinally through the slotted element.

Testing was then delayed until September 1976 when another replacement unit (the Discostrainer) became available. The Discostrainer incorporated a two-directional mesh screen and had the same piping arrangement as the Rotostrainer. None of the ten CSO tests after installation of the Discostrainer experienced fiber matting and all lasted 3 hours or longer. These tests (S9-S18) are considered representative of HRF performance and are the most useful for process evaluation. Five tests on RDWS (D25-D29) were conducted after installation of the Discostrainer in an attempt to correlate the HRF system performance with previous tests using the Rotostrainer.

In the fall of 1975, it became evident from the data that there was a lack of correlation between the characteristics of the plant influent grab samples and the filter influent and effluent samples at any period during a filter run since the filter influent came from the well mixed storage tanks. To eliminate this disparity, the pilot plant process flow system was modified to provide piping directly from the screening discharge line to the suction line of the filter influent pump. The standpipe by-passing the storage tanks was kept flooded during filter operation and overflowed into the storage tanks. Thus, the filter influent sample, with a few minutes lag, represented the same sewage as the plant influent, resulting in better correlation of grab sample data. The overflow to the storage tanks continued to be used to prolong the filter runs.

There were other operating problems resulting from the intermittent use of the pilot plant. Growths of algae and slime in the filter column between tests had to be controlled by a 5 gal (19 l) dose of 12 percent hypochlorite solution prior to each test. Difficulties with motors, pumps and broken piping caused several storm tests to be missed. The pilot plant was out of service during the winters of 1975-76 and 1976-77 and breakdowns were most severe during spring plant startup due to ruptured piping.

Two improvements to the pilot plant were made in March 1977. Additional media was provided for a final composition of 60 in. (152 cm) of No. 3 anthracite over 30 in. (76 cm) of No. 612 sand. A static in-line mixer was installed in the filter influent line to provide more thorough dispersion of chemical feeds. The final CSO tests (S14-S18) and RDWS test D-29 were performed after these changes. To keep within the project budgets until May 1976, the storm "alert" period, during which the pilot plant would be manned and operated, was set at normal business hours. Since this schedule resulted in only one in three storms being tested, the alert period was extended in May 1976 to 24 hours on weekdays, and in June, to 24 hours, 7 days/week, until the CSO testing was completed.

The Newtown Creek plant process, flow quantity and quality are atypical of most large treatment facilities due to the relatively large industrial flow component and the absence of primary treatment. The BOD and COD removals effected by the HRF system reflect this high background industrial component and should be cautiously reviewed in the design of a full-scale HRF facility. The SS removals data, however, are representative and should be considered in that light.

CSO TESTING RESULTS

The results of eleven CSO tests with filter runs of three hours or more are given in Tables 3 through 7. All tests utilized constant rate filtration at 16 gpm/ft^2 (40 $m^3/hr/m^2$) except tests S-17 and S-18 which used declining rate filtration and are discussed separately. All tests were begun within two hours after the plant flow increased above dry-weather levels.

The variability of flow of each storm event is an apparent and important factor in the evaluation of CSO results. Based upon an analysis of storm data records from 1948-1975 at the 16 recording rain gages in the New York City-New Jersey metropolitan area, the average storm in New York City has the following characteristics (9); duration - 6.5 hrs, accumulation - 0.375 in. (0.95 cm), intensity - 0.056 in./hr (0.14 cm/hr), and duration between storms - 77 hrs (3.2 days). From Table A-20, which gives characteristics of each storm during tests S-5 through S-18, it is seen that storms S-13, 14, and 16 were of high intensity, and the other storms tested were moderate to low intensity rainflows.

From the results it is apparent that a fairly consistent effluent suspended solids quality can be effected by the filtration system and that efficiency of removals is directly related to the influent SS concentration. Characterization of the sewage solids should be a major criterion in the design and success of an HRF system.

The overall results for SS, when averaged for the nine tests using constant rate filtration were: plant influent 182 mg/l, filter influent 161 mg/l, filter effluent 62 mg/l, for SS removals of 61 percent across the filter and 66 percent across the HRF system.

Grouping the constant rate tests by modes of operation (Table 3)--without chemical feed, with polymer alone, and with polymer and alum--the average SS removals (across the filter/system) were 55 percent/62 percent, 63 percent/67 percent and 67 percent/69 percent, respectively.

Polymers enhance removals by flocculation, by more rapid formation of the filter pre-coat or by a combination of both. The results of the constant rate filtration tests show that the cationic Betz 1150 gave the best results of the polymers tested. When used alone (test S-13) this polymer effected 68 percent removal of SS and when utilized in combination with alum (tests S-14, 16), averaged 72 percent SS removal across the filter.

The influent concentrations should be evaluated in addition to removal rates to provide an accurate picture of HRF process performance since higher influent concentrations allow greater removal efficiencies. This can be shown from the results of eleven representative CSO tests as given on Table 4. The four CSO events occurring on a weekend averaged 51 percent filter removal of SS while the remaining events, occurring on weekdays, averaged 68 percent removals. The length of filter run and the filter effluent quality (66 mg/l weekend, 58 mg/l weekday) averages were essentially the same for each period. Since average background influent SS loading on weekdays was much higher (179 mg/l) than that on weekends (135 mg/l), much of the apparent difference in filtration efficiency can be attributed to the higher influent strengths on weekdays. This finding is supported by the results of the Cleveland CSO testing (6).

The final two CSO tests were performed in a declining rate filtration mode; test S-17 used Purifloc A-23 polymer alone and S-18 used Betz 1150 polymer in combination with alum. The initial flux was 24 gpm/ft^2 (60 m^3/hr/m^2) dropping to 13 gpm/ft^2 (32 m^3/hr/m^2) for test S-17 after six hours, and to 7 gpm/ft^2 (17 m^3/hr/m^2) for test S-18 after 10 hours. The poor

TABLE 3. CSO SS REMOVALS VS CHEMICAL ADDITIONS

Run No.	Chemical Dosage (mg/l)	Duration (hr)	Plant Influent (mg/l)/(lb)	Filter Influent (mg/l)/ (lb)	Filter Effluent (mg/l)/ (lb)	Removal Filter (%)	Removal System (%)
Without Chemicals							
S-4B	0	3.0	112/12.1	105/11.3	30/3.2	71	73
S-9	0	3.0	152/16.4	136/14.5	61/6.7	55	60
S-10	0	5.5	189/37.4	149/29.5	60/11.9	60	68
S-15	0	8.0	198/57.0	172/49.5	87/25.1	49	56
Average		5.0	175/30.7	150/26.2	67/11.7	55	62
With Polyelectrolyte							
S-11	0.5 polymer**	6.0	99/21.4	94/20.3	49/10.6	48	51
S-17*	1.4 polymer	6.0	276/74.6	248/67.0	110/29.7	56	60
S-13	1.0 polymer	6.5	311/72.8	266/62.3	85/19.9	68	73
Average		6.0	209/47.1	183/41.3	68/15.3	63	67
With Alum and Polyelectrolyte							
S-12	15 alum 0.5 polymer	4.0	133/19.2	122/17.6	55/7.9	55	59
S-14	35 alum 2 polymer	3.0	185/20.0	192/20.7	58/6.3	70	-
S-16	17 alum 1.3 polymer	4.0	147/21.2	126/18.2	31/4.5	75	79
S-18*	15 alum 1.0 polymer	10.0	174/62.7	158/56.9	67/24.1	58	61
Average		4.0	152/20.1	143/18.8	47/6.2	67	69

The average values were calculated by weighting each filter run by its duration.

* Declining rate filtration tests, S-17 had a 20 gpm/ft^2 average flux, S-18 a 16 gpm/ft^2 average flux; these tests were not included in the averaging of SS data. All other tests were constant rate filtration, 16 gpm/ft^2 flux.

** Polymers used were: for S-11 and S-12, Hercofloc 1054 (anionic); for S-17, Purifloc A-23 (anionic); and for S-13, S-14, S-16 and S-18, Betz 1150 (cationic).

TABLE 4. CSO SS REMOVALS WEEKDAY-WEEKEND COMPARISON

Run No.	Chemical Dosage (mg/l)	Duration (hr)	Plant Influent (mg/l)	Filter Influent (mg/l)	Filter Effluent (mg/l)	Removal Filter (%)	Removal System (%)
Weekday Tests							
S-4B	0	3.0	112	105	30	71	73
S-10	0	5.5	189	149	60	60	68
S-17*	1.5 polymer **	6.0	276	248	110	56	60
S-13	1.0 polymer	6.5	311	266	85	68	73
S-14	35 alum 2 polymer	3.0	185	192	58	70	-
S-16	17 alum 1.3 polymer	4.0	147	126	31	75	79
S-18*	15 alum 1.0 polymer	10.0	174	158	67	58	61
Average		4.5	206	179	58	68	72
Weekend Tests							
S-9	0	3.0	152	136	61	55	60
S-15	0	8.0	198	172	87	49	56
S-11	0.5 polymer	6.0	99	94	49	48	51
S-12	15 alum 0.5 polymer	4.0	133	122	55	55	59
Average		5.2	151	135	66	51	56

The average values were calculated by weighting each filter run by its duration.

* Declining rate filtration tests, S-17 had a 20 gpm/ft^2 average flux, S-18a 16 gpm/ft^2 average flux; these tests were not included in the averaging of SS data. All other tests were constant rate filtration, 16 gpm/ft^2 flux.

** Polymers used were: for S-11 and S-12, Hercoflox 1054 (anionic); for S-17, Purifloc A-23 (anionic); and for S-13, S-14, S-16 and S-18, Betz 1150 (cationic).

results with declining rate filtration appear to be due to the design of the pilot plant which did not allow maintenance of a constant pressure head in the gravity filter. Sudden surges in head forced solids to pass through the filter (to shear). An overflowing standpipe ahead of the filter would have been necessary to maintain a constant pressure head. Tests S-17 and 18 therefore have not been used in calculating average results.

Figure 8 shows HRF treatment efficiencies based on SS mass removals or capture per square foot of filter surface for the CSO tests. It is apparent from the figure that test S-13 provided superior mass removals as compared to the other tests, giving a strong indication of filter operation under severe stress. The data from S-13 appears to be the most significant collected from all the CSO tests since during this storm the upstream sewer regulators remained open, channeling most of the 1.15 in. (2.9 cm) rainflow directly to the Newtown Creek plant. Furthermore, S-13 was the only storm in which the precipitation was constant and intense throughout the filter run. During all other storms tested, the rains were of either short duration or of low intensity preventing a thorough stressing of the HRF system.

Table 5 presents average SS mass captures obtained across the filter during all CSO tests of at least 3 hours duration (excluding S-17 and S-18) and the averages for tests S-13, 14 and 16 which used more optimal chemical feeds and occurred during the storms of greatest intensity.

TABLE 5. AVERAGE MASS CAPTURE OF CSO SS

	Capture per Filter Surface		Capture per Media Volume	
CSO Test Nos.	$lb/ft^2/run$*	$lb/ft^2/hr$	$lb/ft^3/run$**	$lb/ft^3/hr$
S4B, S9-16	3.7	0.76	0.54	0.11
S-13, 14, 16	5.2	1.2	0.76	0.17

* 1 lb/ft^2 = 4.88 kg/m^2
** 1 lb/ft^3 = 16.02 kg/m^3

Settleable solids removal was consistently better than 95 percent in the filter (see Table 6). The influent levels ranged from 1.0 to 6.0 ml/l and effluents from 0.0 to 0.2 ml/l in composite samples from seven CSO and two RDWS filtration tests.

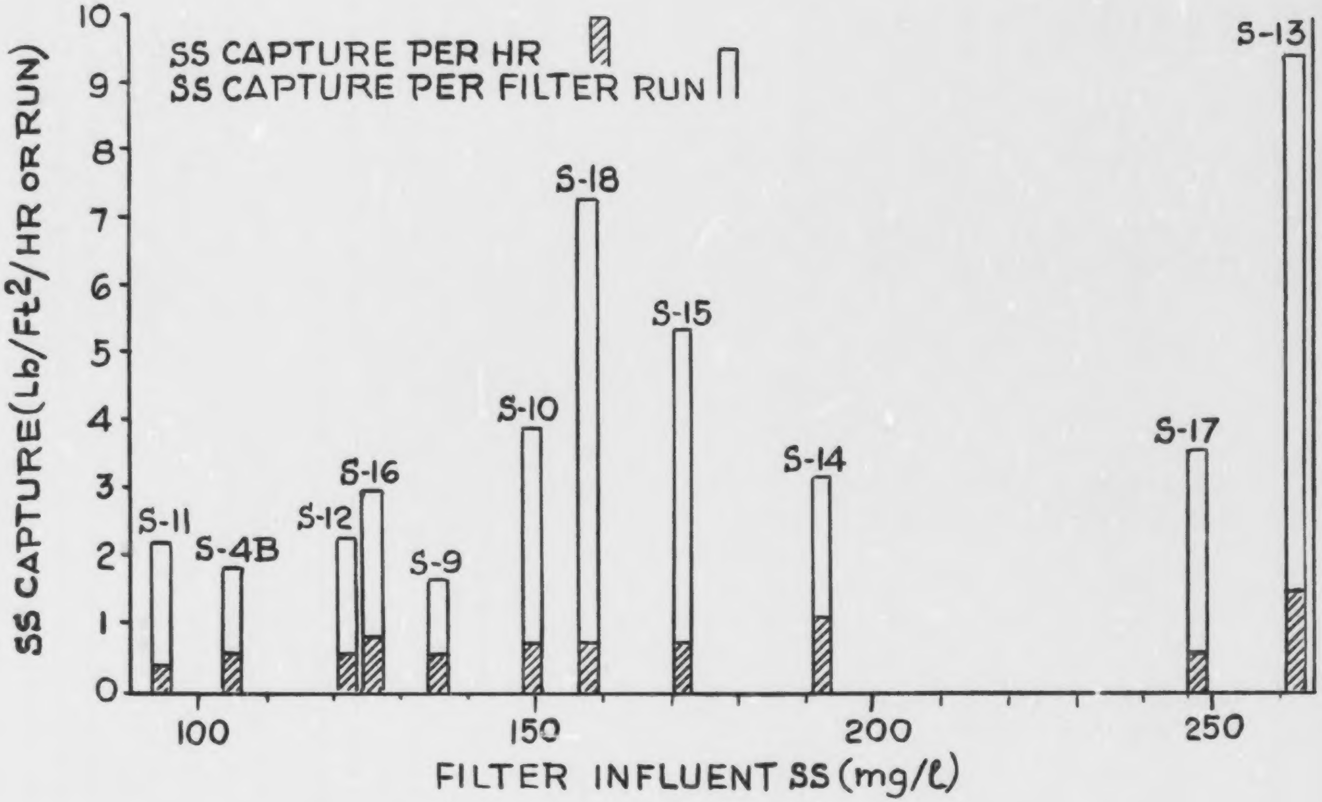


FIGURE 8 - CSO SS MASS CAPTURES PER UNIT FILTER AREA AND TIME

TABLE 6. SETTLEABLE SOLIDS REMOVALS

Run No.	Plant Influent (ml/l)	Filter Influent (ml/l)	Filter Effluent (ml/l)	Filter Removal (%)
S10	5.0	2.0	0.0	100
S11	3.0	0.5	0.0	100
S12	4.0	2.0	0.0	100
S13	5.5	2.2	0.1	95
S14	4.5	6.0	0.2	97
S15	4.0	2.0	<0.1	>95
S16	4.0	1.2	0.0	100
S17*	7.0	3.5	0.1	97
S18*	5.0	1.0	<0.1	>90
S28	--	1.7	0.0	100
D29	2.5	4.5	0.0	100

* Results from runs S17 and 18 (declining rate filtration) are not used in data averaging (see pp.35-36)

S - indicates CSO test
D - indicates RDWS test

Organic pollutant removals across the filter are shown in Table 7. BOD removal trends are consistent with the SS removals, 32 percent average removal for all tests (29 percent for weekend flow tests, 35 percent for weekday flow tests) or averaged for the three modes of operation (no chemical, one chemical, two chemical aids), 27 percent, 35 percent and 38 percent, respectively. COD removals (42 percent general average) also varied for the three modes of operation, 32 percent, 46 percent, 50 percent, respectively; and weekend versus weekday showed some change, 37 percent and 41 percent, respectively.

The results of composite samples were not used in the calculation of average values of SS, BOD and COD. SS results were calculated by flow-weighted averaging of the results of individual grab samples. BOD and COD results were from averages of the grab samples. Composite sample results, for SS especially, were often at variance with the flow-weighted averages. Composite sample results are given in Table A-5. The variation of CSO characteristics is further indicated by the fact that individual grab samples of filter influent often had greater SS concentrations than plant influent samples.

TABLE 7. CSO BOD AND COD REMOVALS

		BOD			COD		
Run No.	Chemical Dosage (mg/l)	Filter Influent (mg/l)	Filter Effluent (mg/l)	Removal (%)	Filter Influent (mg/l)	Filter Effluent (mg/l)	Removal (%)
Without Chemicals							
S-4B	0	132	98	26	297	192	35
S-9	0	126	91	28	226	161	29
S-10	0	-	-	-	350	251	28
S-15	0	134	99	26	267	170	36
	Average	131	96	27	285	193	32
With Polyelectrolyte							
S-11	0.5 polymer**	119	79	34	205	132	36
S-17*	1.5 polymer	153	111	27	456	263	42
S-13	1.0 polymer	139	90	35	385	187	51
	Average	129	84	35	295	159	46
With Alum and Polyelectrolyte							
S-12	15 alum 0.5 polymer	67	49	27	190	98	48
S-14	35 alum 2 polymer	97	53	45	312	136	56
S-16	17 alum 1.5 Polymer	90	58	36	223	125	44
S-18*	15 alum 1.0 polymer	192	106	45	280	182	35
	Average	85	53	38	242	120	50

* Declining rate filtration tests, S-17 had a 20 gpm/ft^2 average flux, S-18 a 16 gpm/ft^2 average flux; these tests were not included in the averaging of data. All other tests were constant rate filtration, 16gpm/ft^2 flux.

**Polymers used were: for S-11 and S-12, Hercofloc 1054 (anionic); for S-17, Purifloc A-23 (anionic); and for S-13, S-14, S-16 and S-18, Betz 1150 (cationic).

Ultimate (20 day) BOD were analyzed from composite samples only and filter removals were comparable to BOD removals in the same composites, ranging 27-39 percent (Table A-6). Chemical dosing improved removals but there was no distinction among types of polymer. The UBOD values were generally 2 to 5 times the corresponding BOD (five-day).

Results for FBOD and FCOD indicate no significant removals of dissolved organic material by filtration with or without chemical aids. The filtered values ranged 25-50 percent of the total BOD and COD values; composites (Tables A-5 and A-6) and grab samples (A-7) showed the same trends. In the CSO and RDWS tests there was no apparent relation between filter removals of SS, BOD or COD and proportion of dissolved organic material.

VSS data appears on Table A-8. The percentage of volatiles varied widely in the influent and effluent samples. The results appear scattered and inconclusive. In future HRF studies, VSS removals should be evaluated more thoroughly.

RDWS TESTING RESULTS

Twenty-four consecutive filter runs (D1-24) operating continuously were conducted with RDWS on the 30-in. filter column in October 1975. Table A-2 lists the results of each run, and Table 8 contains average results grouped by chemical feeds and flux.

The results of the consecutive runs indicate that at a flux of 8 gpm/ft^2 (20 m^3/hr/m^2) without chemical feed (D1-4) and 12 gpm/ft^2 (30 m^3/hr/m^2) with 0.5 mg/l of polyelectrolyte (D5-14) average SS removals of 67 percent can be attained across the filter. Individual filter test SS removals ranged from 60 to 74 percent at 8 gpm/ft^2 (20 m^3/hr/m^2) and 50-77 percent at 12 gpm/ft^2 (30 m^3/hr/m^2). BOD removals across the filter at these flux values averaged 30 percent and 39 percent, respectively. Five filter runs (D15-19) were conducted at the flux of 12 gpm/ft^2 (30 m^3/hr/m), with 0.5 mg/l polyelectrolyte and 10 mg/l alum feed. Filter removals averaged only 64 percent for SS and 23 percent for BOD. Thus the alum-polymer addition did not provide improved percentage removals over use of polymer alone. This conclusion is supported by the results of the final RDWS test with the same flux and chemical feed (test D-29 effected 62 percent removal of SS and 36 percent removal of BOD).

Five tests (D20-24) were conducted at 12 and 16 gpm/ft^2 (30 and 40 m^3/hr/m^2) flux values. The results indicate lower SS removals at the higher flux;

TABLE 8. RDWS SS BOD AND COD REMOVALS VS. FLUX AND CHEMICAL ADDITIONS

Filter Run Nos.	Duration (hr)	Flux gpm/ft^2	Chemical Dosage (mg/l)		SS				BOD				COD			
					Concentration (mg/l)			Removal(%)	Concentration (mg/l)			Removal(%)	Concentration (mg/l)			Removal(%)
			Poly	Alum	Plant	Fi	Fe	Filter	Plant	Fi	Fe	Filter	Plant	Fi	Fe	Filter
D1-4	5.3	8	0	0	141*	129	42	67	258*	225	157	30	340*	270	195	28
D5-14	5.3	12	0.5 (Z)**	0	-	125	41	67	-	140	86	39	-	265	174	34
D15-19	6.0	12	0.5 (M)**	10	136	147	53	64	143	141	109	23	325	310	200	35
D20-21	5.0	16	0.5 (P)**	10	179*	175	78	55	185*	198	138	30	310*	350	255	27
D22	8.0	12	0	25	-	116	37	68	-	130	110	15	295	295	165	44
D23	4.0	16	0	19	252	193	81	58	280	230	205	11	485	485	330	32
D24	6.0	12	1.0 (P)**	0	134	167	75	55	195	170	140	18	395	395	285	28
D26	8.0	12	0	0	131	101	39	61	183	174	108	38	340	270	181	33
D29	5.0	12	1.0 (B)**	10	164	146	56	62	173	169	102	40	356	329	210	36
D25	4.0	16	0.5 (H)**	0	148	121	43	65	134	119	88	26	325	268	181	32
D27	3.0	16	0.5 (H)**	30	175	152	30	80	195	171	121	29	351	315	197	34

* Average values based on only 1 or 2 samples

** Z - Zetag 92 (cationic), M - Magnifloc 561C (cationic), P - Purifloc A-23 (anionic), B - Betz 1150 (cationic), H - Hercofloc 1054 (anionic), Fi - Filter Influent, Fe - Filter Effluent

Last four filter runs were individual tests, not in continuous series as runs D1-24.

however, chemical feed and flux varied widely among tests. Figure 9 presents SS removals vs. flux for the RDWS runs grouped by chemical feed.

Five subsequent tests (D25-29) were performed in 1976 and 1977 attempting to correlate the filtration data using the different screening devices and to evaluate the screens themselves. The tests were conducted at varying flux and chemical feeds; the filtration data appears scattered and is therefore presented on Tables 8 and A-2 but not further interpreted.

The data collected across the screening device (the Discostrainer) indicate that SS removals of 18 and 23 percent were attained with the 70 mesh (210 micron) screen (tests D25 and 26) and 11-19 percent removals were attained with the 40 mesh (420 micron) screen (D27-29).

Throughout the RDWS testing, the filter effluent SS concentrations averaged 49 mg/l and within the range of 30-75 mg/l for 86 percent of the tests. All consecutive runs at 8-12 gpm/ft^2 (20-30 m^3/hr/m^2) had filter effluent levels below 75 mg/l and averaged 44 mg/l.

Figure 10 graphically shows HRF treatment efficiency based on SS mass capture per square foot of filter surface for the RDWS tests. The data is also presented on Table 9, categorized by flux and chemical feed and including mass capture per cubic foot of media volume.

COD results are listed in Tables 8 and A-2. Removals averaged 32 percent and ranged from 20 to 53 percent. As has been noted before, the Newtown Creek plant influent has a large industrial component and cannot be considered typical of municipal sewage with respect to COD.

BACKWASHING/CONCENTRATE EVALUATION

The most effective operating procedure tested for backwashing required the use of air in combination with water at a rate of 12 gpm/ft^2 (30 m^3/hr/m^2) for 2 to 4 min of scrubbing, and then water alone at 35 gpm/ft^2 (87 m^3/hr/m^2) for 6 to 10 minutes of flushing and backwash discharge. This water flushing rate was the maximum obtainable using the backwash pump. The specific duration of backwashing and volume of water depended on the loading of trapped solids from each test. Effective cleaning could be obtained by the use of backwash water volumes of 6 percent of the wastewater filtered in an average run. Tables A-3 and A-4 give data for CSO and RDWS runs, respectively. Full-scale HRF facilities would use filter effluent or secondary treatment effluent for filter backwashing for most economical operations. This is the common

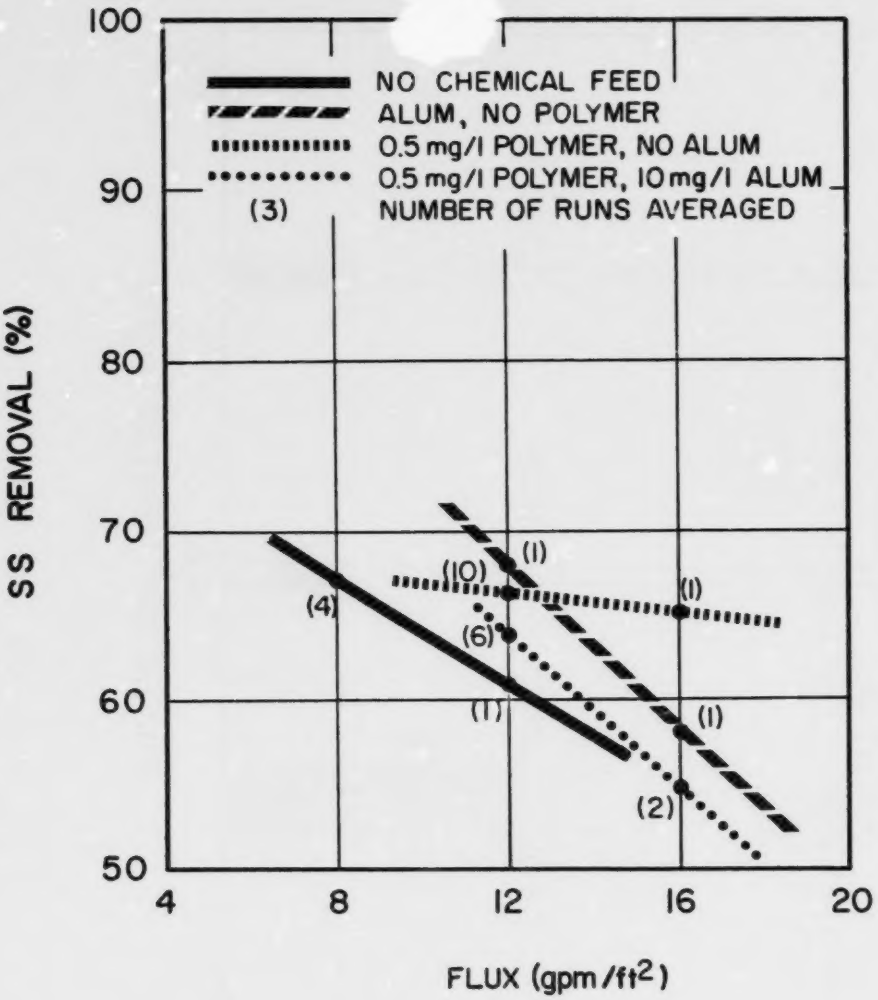


FIGURE 9-RDWS SUSPENDED SOLIDS FILTER REMOVAL AVERAGES

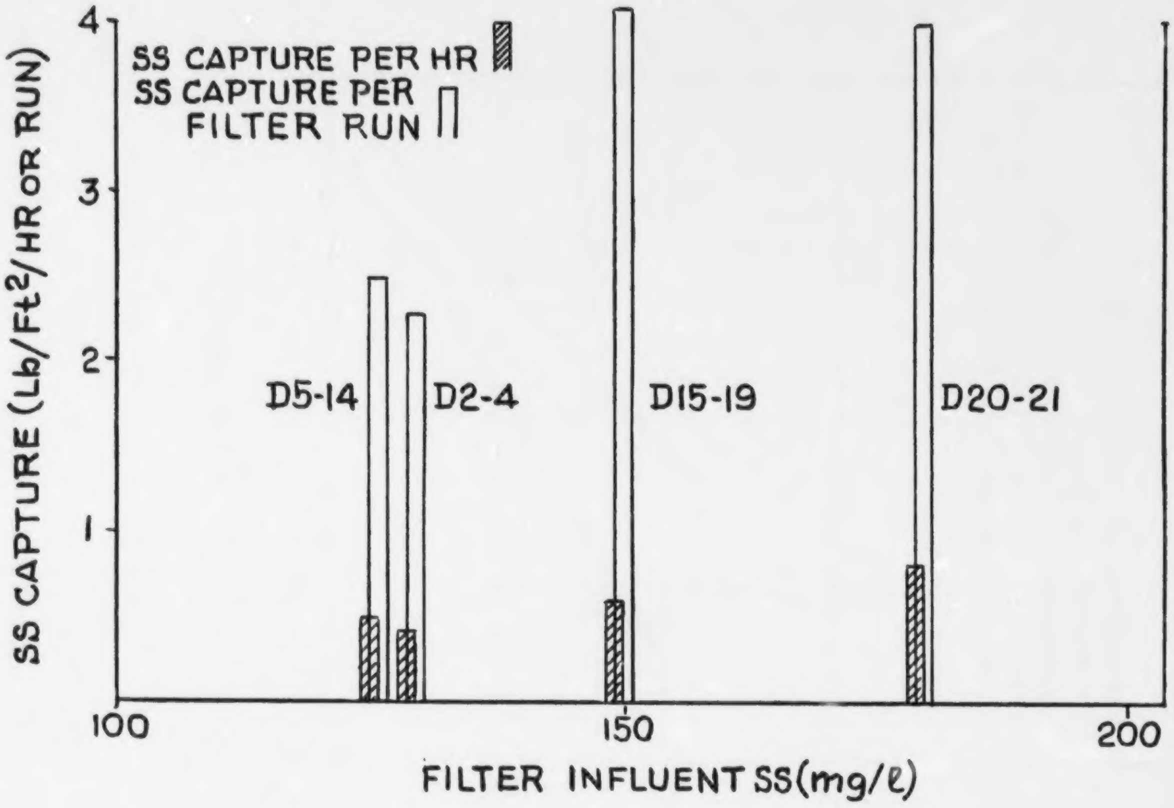


FIGURE 10 - RDWS SS MASS CAPTURES PER UNIT FILTER AREA AND TIME

TABLE 9. AVERAGE MASS CAPTURE OF RDWS SS

RDWS Test Nos.	Capture per Filter Surface lb/ft^2/run*	Capture per Filter Surface lb/ft^2/hr	Capture per Media Volume lb/ft^3/run**	Capture per Media Volume lb/ft^3/hr
D-2 to 4 (8 gpm/ft^2, no chemicals)	2.3	0.37	0.36	0.06
D-26 (12 gpm/ft^2, no chemicals)	3.0	0.37	0.46	0.06
D-5 to 14 (12 gpm/ft^2, 0.5 mg/l poly)	2.5	0.50	0.39	0.08
D-15 to 19 (12 gpm/ft^2, 0.5 mg/l poly, 10 mg/l alum)	4.1	0.57	0.63	0.09
D-20 to 21 (16 gpm/ft^2, 0.5 mg/l poly, 10 mg/l alum)	4.0	0.80	0.61	0.12

* 1 lb/ft^2 = 4.88 kg/m^2

** 1 lb/ft^3 = 16.02 kg/m^3

practice at HRF facilities used in industrial wastewater treatment and for secondary effluent polishing in Ashvale, England (2).

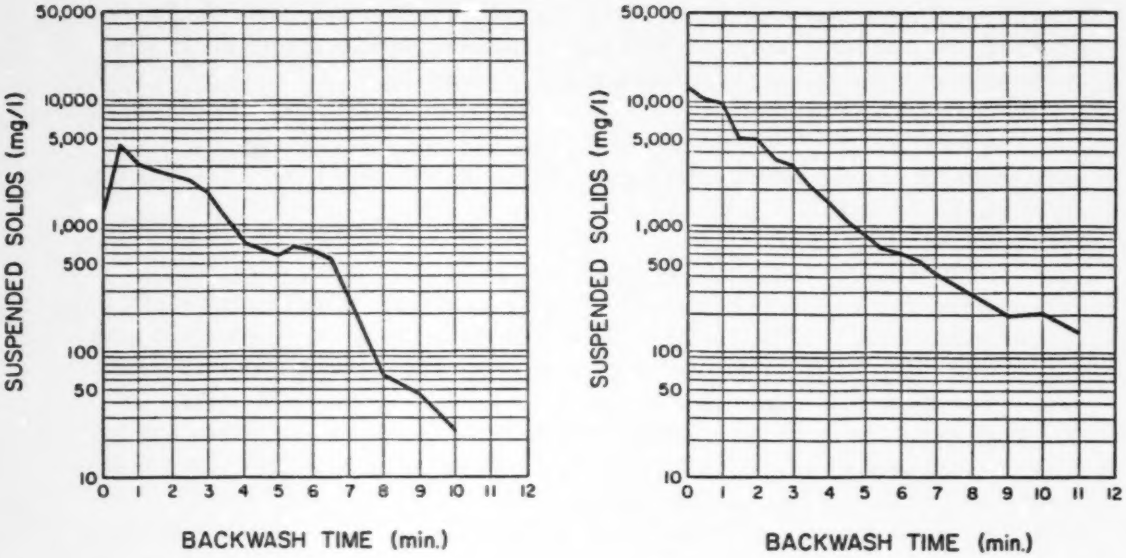
The most important factor in effective cleaning was a complete agitation of the media (bed fluidization) during the scrubbing and flushing operations. Problems early in the test were caused by breakage of the equalizing nozzles in the filter bottom plate. This produced an uneven distribution of water and air and prevented sections of the media from being fluidized effectively. Repair of the nozzles (Spring 1976) corrected this problem.

The supply of air was limited to approximately 5 $scfm/ft^2$ (1.5 $m^3/min/m^2$) of filter surface throughout the program; this was the maximum flux that could be supplied by the Newtown Creek plant. The available air supply appeared to be inadequate for optimal scrubbing; it was observed that the air feed rate was uneven and only portions of the media were agitated at any one time. A higher flux, 8-12 $scfm/ft^2$ (2.4-3.7 $m^3/min/m^2$), would have been more effective in continuously agitating all sections of the filter and should have allowed use of less water for scrubbing and flushing. Wall effects could have hampered effective air scrubbing.

SS mass balances are given in Tables A-3 and A-4. The mass of SS calculated as removed in the filter column during each run was determined by flow weighting, assuming constant SS concentrations in the filter influent and effluent for the time between each sample. The actual amounts recovered in the backwash were determined by flow weighting the SS concentrations in the backwash grab samples. When only composite samples were available, these were used for the mass balance determination. Generally there was agreement within 25 percent between calculated filter removal and actual backwash recovery; this approximates the error expected in sampling and analysis.

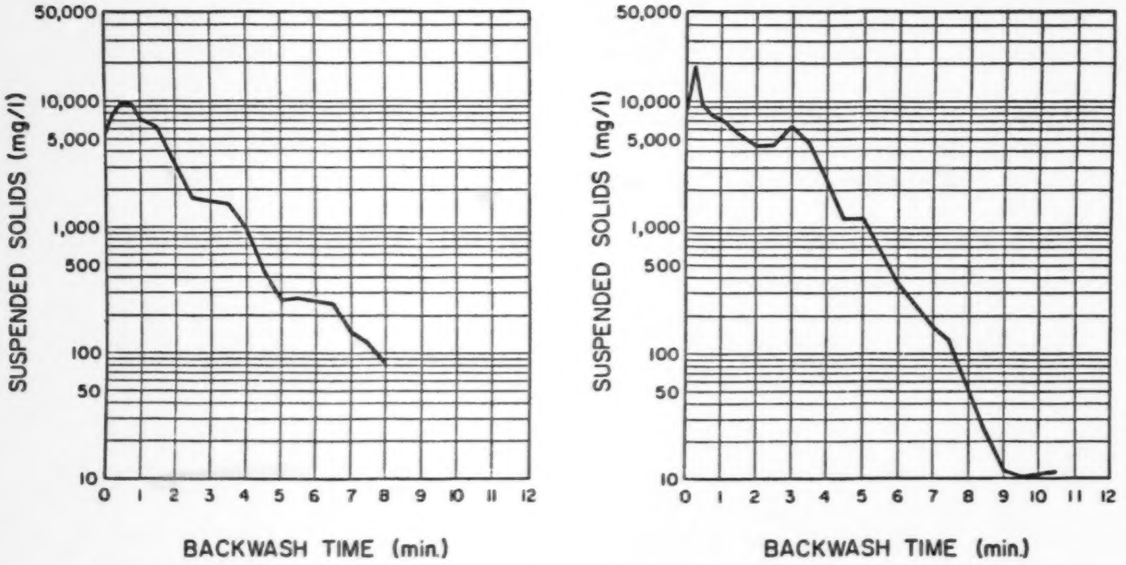
Profiles of backwash effluent SS concentration with discharge time are given in Figure 11. The SS are on a logarithmic scale and show a fairly continuous decrease after reaching maximums, during the initial 0.5 minute, of 4,400 to 13,100 mg/l. The average SS concentrations in the backwash effluent ranged from 770 to 4,060 mg/l, with a median of 2,353 mg/l. Profiles of backwash effluent SS from the Cleveland testing show similar values of SS maximum concentration, however, a greater portion of the total SS was discharged during the first 3-4 min indicating an an apparent greater effectiveness in media scrubbing and flushing.

Other average characteristics of backwash effluent composites for CSO runs of 3 hours or more (Table A-9) are a 65 percent volatile component of the SS, BOD 905 mg/l, COD 2,445 mg/l, and Set. S. 69 ml/l. The



FILTER BACKWASH FROM RUN S-12

FILTER BACKWASH FROM RUN S-13



FILTER BACKWASH FROM RUN S-17

FILTER BACKWASH FROM RUN S-18

FIGURE 11 - FILTER BACKWASH EFFLUENT SUSPENDED SOLIDS VS TIME

average volatile component of SS in the filter influent (Table A-8) was greater (68 percent) than the average volatile component of SS in the backwash for the same CSO tests (62.5 percent).

For the available RDWS backwash analyses, the average SS concentrations were SS 2,215 mg/l, BOD 1,150 mg/l, COD 2,560 mg/l and Set. S. 88 ml/l.

The sludge density index (SDI) and sludge volume index (SVI) were determined for each backwash composite sample. The average SDI for all samples was 3.5 (SVI = 29). For RDWS tests the average SDI was 2.9 (SVI = 35). The settled sludge from the SDI determinations was separated from the supernatant and used in dewaterability tests. In the Buchner filtration test, after 90 seconds of applied vacuum the average volume passing the funnel was 110 ml. In the filter leaf test (using 250 ml samples vacuum filtered through filter leaf cloth), the resulting cake averaged 36 percent dry solids, with all but one filtrate sample visibly clear. Data from the sludge tests are contained in Table A-10.

METALS REMOVAL

Testing for metals removal became an important aspect of the HRF program during 1976-77. Composite samples of influent, effluent and backwash were analyzed for seven metals: cadmium, chromium, copper, lead, mercury, nickel and zinc. Some arsenic analyses were also performed. Discostrainer sludge samples were also analyzed for metals. Appendix Tables A-11 through A-18 present the metals results, including percent and mass removals.

In April 1976 several tests were conducted on the parallel 6 in. (15 cm) columns to attempt metals precipitation at 24 gpm/ft^2 (60 m^3/hr/m^2) with additions of lime and/or polymer. While SS removals of 79 percent were obtained, neither polymer feed alone nor lime addition to pH 8.5 combined with polymer, significantly affected metals removal.

For all tests, there is no indication of improved metals removal with the use of polymer and/or alum aids. No correlations appear between metals removal and SS removal or influent metal concentrations. For each metal, low influent concentrations were treated as effectively as higher concentrations, and the influents varied greatly. For all CSO tests with filter influent and effluent sampling (S7-18), the average results are given in Table 10, including mass removals per unit filte surface area per filter run (average 5.1 hr duration).

TABLE 10. METALS REMOVAL AVERAGES

Metal	CSO/RDWS Treatment Results* Filter Influent (mg/l)	Filter Effluent (mg/l)	Removal (%)	Calculated Removal $(lb/ft^2/run)x10^{-3}$
Cadmium	0.023/0.007	0.010/0.006	58/17	0.55/0.03
Chromium	0.33/0.47	0.24/0.34	27/28	4.1/3.8
Copper	0.33/0.30	0.22/0.20	35/33	5.3/3.1
Lead	0.57/0.4	0.32/0.3	44/25	11./3.0
Mercury	0.001/0.002	0.0005/0.001	50/50	0.03/0.02
Nickel	0.19/0.14	0.14/0.10	26/29	2.3/1.2
Zinc	0.42/0.43	0.27/0.37	36/14	6.4/1.8

* CSO results based on 11 filter runs (S7-18, excl. S9) by flow-weighted averaging. There was much variation among individual runs. RDWS results based on 1 filter run (D-29) and are inserted for a comparison of relative magnitudes of concentrations only. $lb/ft^2 \times 10^{-3} = 4.88\ gm/m^2$.

Arsenic was analyzed in a few tests but removals were negligible. Samples of one RDWS test (D-29) were analyzed for metals. Influent metals concentrations were similar to those found in CSO but no firm conclusions can be drawn on comparative removal efficiencies.

Backwash composite samples contained relatively low concentrations of mercury and nickel, and for all metals the mass balances (Tables A-11 to A-18) indicated poor correlation between calculated filter removal and actual recovery in the backwash.

The Discostrainer sludge cakes appeared to contain high levels of heavy metals (see Table 9) but insufficient data is available to make conclusions on removals. Mass balances of metals are not possible since sludge cake volumes were not determined.

ROTARY SCREENING

There was no specific test program to evaluate or compare the effectiveness of the Rotostrainer or Discostrainer. No analyses were made of the effluent directly from the screens and the difference between plant influent and filter influent samples cannot be effectively used to measure screen efficiency for the Rotostrainer especially since, as previously discussed, the time lag between samples prevented close correlation between them. However, from the data on Table A-1, the Discostrainer with a 40 mesh (420 micron) screen appeared to have effected a fairly consistent SS removal of 10 percent from the plant influent which averaged 190 mg/l during seven CSO tests. The Discostrainer with a 70 mesh (210 micron) screen averaged 16 percent removal of SS during two CSO tests in which the plant influent averaged 171 mg/l. The superiority of the Discostrainer over the Rotostrainer for CSO treatment was apparent from the improved HRF performance when the Discostrainer was used.

Samples of the solids (sludge) removed by the Discostrainer were taken during four runs and were analyzed for dry solids and metals (Table 11). The dry solids content of the sludge ranged 11.8 to 18.7 percent, with the VSS proportion ranging 79.0-87.4 percent.

DISINFECTION

Tests of the high-rate disinfection equipment were made during three RDWS runs, using a filter effluent sidestream for about one hour during the final two hours of the run. Table 12 presents the data for all tests.

The disinfection unit was reported to operate (7) at a flow of 20 gpm (1.26 l/s) but, unfortunately, flows over 10 gpm (0.63 l/s) exceeded the capacity of the V-notch weir at the end of the rapid mixing chamber. The tests therefore had to be conducted at 10 gpm resulting in an approximate 9 minute detention time within the baffled contact tank. The hypochlorite dosage was fed by gravity from a small tank and mechanically mixed with the flow in the mixing chamber (40 seconds detention time) before overflowing into the baffled contact tank.

Figure 12 indicates that a dosage of approximately 7 mg/l hypochlorite (as chlorine) will provide satisfactory disinfection in meeting the New York State standard of 200 fecal coliforms per 100 ml effluent.

During several tests of RDWS and CSO, samples of pilot plant influent and filter effluent were analyzed for total and fecal coliforms using the multiple tube technique. The results, given on Table A-19, show inconsistencies in removals. This may be due to faulty sampling technique or variability of background densities.

TABLE 11. DISCOSTRAINER SLUDGE ANALYSES

Run No.	Total Dry Solids %	Volatile Dry Solids %	Cadmium mg/l	Chromium mg/l	Copper mg/l	Lead mg/l	Mercury mg/l	Nickel mg/l	Zinc mg/l
S-14	18.7	15.0	0.5	44.	58.	75.	0.08	10.	89.
S-17	11.8	9.7	5.0	20.	16.	30.	0.10	4.	50.
S-18	14.4	11.4	0.58	25.	32.	60.	0.10	4.	63.
D-29	14.2	12.4	0.42	22.	15.	20.	0.01	3.	37.
Average	14.8	12.1	1.63	28.	30.	46.	0.07	5.	60.

Discostrainer used a 40 mesh (420 micron) screen.

NOTE: 1. **Volatile dry solids expressed as percent of total sludge sample.**

2. **Metals concentrations expressed as mg/l of total sludge sample.**

TABLE 12. DISINFECTION RESULTS

Test Date	Influent FC/100 ml	Cl_2 Dosage (mg/l)	Contact Time (min)	Cl_2 Residual (mg/l)	Surviving FC/100 ml
11/4/76	--	10	9	0.7	4
11/4/76	--	30	9	1.5	1
11/18/76	1.0×10^6	5	9	0.3	300
11/18/76	0.9×10^6	10	9	6.0	22
11/18/76	1.0×10^6	20	9	12.0	0
4/12/77	1.4×10^6	7	9	0.2	1000
4/12/77	1.1×10^6	15	9	7.0	2
4/12/77	1.2×10^6	20	9	12.0	1

NOTE:
1. All tests used filtered RDWS
2. FC is fecal coliforms
3. Bacterial analyses by membrane filter technique.
4. Dosage given as chlorine equivalents.
5. Chlorine residual determined by a visual comparator using orthotolidine.
6. In the rapid mixing chamber $G = 1050\ sec^{-1}$ and $Gt_d = 42,000$; in the baffled contact tank $G = 25\ sec^{-1}$ and $Gt_d = 12,000$.

IN-LINE CHEMICAL MIXING

There was no specific sampling effort to evaluate the effectiveness of the static in-line mixer since the mixer was installed late in the project and sufficient data could not be collected to provide for evaluation. Further testing should be conducted to evaluate alternate mixing techniques towards optimizing chemical cost effectiveness.

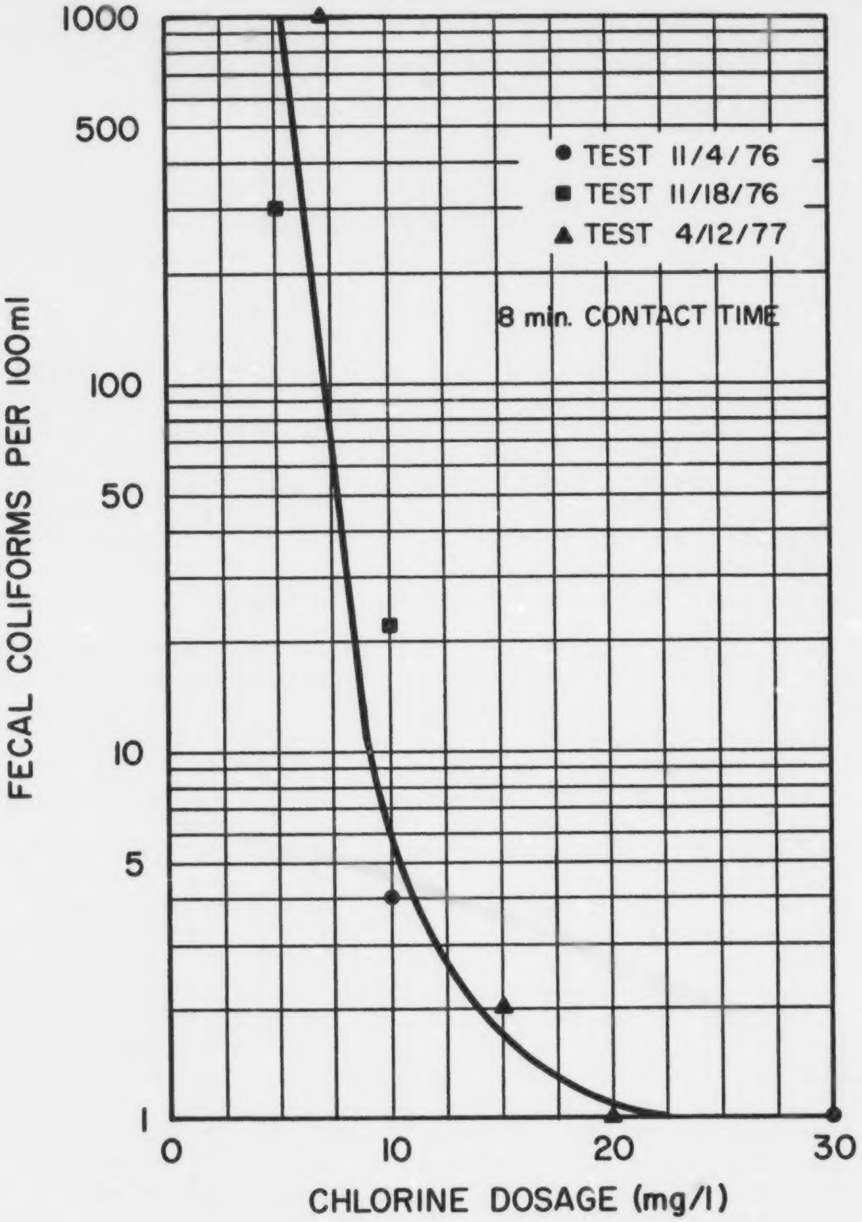


FIGURE 12 - DISINFECTION VS CHLORINE DOSAGE

SECTION 7

FULL-SCALE HRF INSTALLATIONS

ADAPTABILITY OF FUNCTION

The HRF system can be designed for existing or proposed sewer systems, both separate and combined. In urban areas, control of pollutants from separated systems is more expensive and less efficient than treatment of combined sewer flows (10). An HRF system designed to handle the storm flow of a separate sewer system would be automated for immediate response to flow increases. The treatment scheme could include one central HRF plant or several plants located at strategic points on the storm sewer system. Since storms are commonly short duration, high intensity events, the HRF plant should be designed to capture and effectively treat a desired peak storm flow.

Use of existing storage capacity or added storage facilities must be considered in the design for optimizing the size of the HRF system. The excessive storm flow, if stored, would be treated by the HRF system after the storm event or at a time in the day most cost-effective for operation, e.g., during hours of off-peak electrical power demand. Selection of storm flow storage capacity in the design of an HRF system is further discussed in reference 6.

For existing combined sewer systems, HRF can be used in a dual-treatment capacity filtering RDWS between CSO events. During CSO the existing sewage treatment plant will treat a portion of the flow and the HRF system, utilized in parallel operation as a supplemental facility will treat the balance of the flow. Using HRF systems in a dual capacity provides additional cost benefits. The system would operate throughout the year, automatically switching filtration modes, and since the HRF system would be located adjacent to the existing sewage treatment plant, it would provide primary treatment supplementing existing primary units. In overloaded sewage treatment plants, the reduced loadings of primary effluent, resulting from supplementary HRF treatment, would improve the efficiency of subsequent secondary treatment and sludge handling. A discussion of area requirements and cost benefits of using HRF vs. clarifiers in primary treatment of RDWS is contained in Section 8.

HRF can also be used to upgrade existing sewage treatment plants by polishing secondary effluent. This application of HRF has been successfully tested in a pilot plant in Cleveland (11) and a full-scale filter plant for secondary polishing is now in operation in England as discussed in the Introduction. A finer filter medium (No. 2 anthracite) has been found more effective for this function.

In the design of new sewage treatment plants for combined sewer systems, HRF can be incorporated as a dual-treatment system or for a triple function providing primary treatment and secondary effluent polishing in separate HRF units during dry weather and, during CSO events, all or part of the units as required would switch to CSO filtration. The HRF system for secondary polishing would be used only for treatment of that portion of CSO beyond the capacity of the primary units.

FULL-SCALE DESIGN CONSIDERATIONS

In the Newtown Creek plant process, flow quantity and quality are atypical of most large treatment facilities due to the relatively large industrial flow component and the absence of primary treatment. The BOD and COD removals effected by the HRF system reflect this high background industrial component and should be cautiously reviewed in the design of a full-scale HRF facility. The SS removals data, however, are more representative and should be considered in that light.

From the results it is apparent that a fairly consistent effluent suspended solids quality can be effected by the filtration system and that efficiency of removals is directly related to the influent SS concentration. Characterization of the sewage solids should be a major criterion in the design and success of an HRF system.

The overall results for SS, when averaged for the nine tests using constant rate filtration were: plant influent 182 mg/1, filter influent 161 mg/1, filter effluent 62 mg/1, for SS removals of 61 percent across the filter and 66 percent across the HRF system.

The influent concentrations should be evaluated in addition to removal rates to provide an accurate picture of HRF process performance since higher influent concentrations allow greater removal efficiencies.

The results of composite samples were not used in the calculation of average values of SS, BOD, and COD. SS results were calculated by flow-weighted averaging of the results of individual grab samples. BOD and COD results were from averages of the grab samples. Composite sample results, for SS especially, were often at variance with the flow-weighted averages. The variation of CSO characteristics is further indicated by the fact that individual grab samples of filter influent often had greater SS concentrations than plant influent samples.

The data collected across the screening device (the Discostrainer) indicate that SS removals of 18 and 23 percent were attained with the 70 mesh (210 micron) screen (tests D25 and 26) and 11-19 percent removals were attained with the 40 mesh (420 micron) screen (D27-29).

As discussed in the testing results section, characterization of the sewage should be a major criterion in the design of an HRF system for use in any of these functions. The influent SS concentrations, industrial component, and fraction of dissolved solids are major characteristics to be reviewed. The selection of a screening device for effective pretreatment will also depend on the specific wastewater characteristics. Therefore, all of these factors must be considered in optimizing the capture capability of the HRF media in full-scale design.

BACKWASH SOLIDS HANDLING

When HRF is used exclusively for treatment of urban storm runoff or CSO, the filter backwash effluent containing the captured solids can be treated at a secondary treatment plant. If the plant is at its daily peak capacity, the backwash effluent could be retained in a holding tank and then added to the sewage treatment plant influent at a controlled rate. A majority of backwash solids would settle in the primary basins as part of the primary sludge.

The backwash effluent from a dual-treatment HRF system should be added to the sludge handling system of a secondary treatment plant, ideally the sludge thickeners. The sludge is suitable for the further processing applied to the plant sludge or processed separately on-site (i.e., dewatered). The rotary screening concentrate would be added to the grit handling system of the secondary plant.

PROCESS SEQUENCE

A conceptual schematic of the HRF system for dual-treatment of CSO and RDWS is presented on Figure 13. The HRF system is considered to constitute the primary treatment portion of a new or existing secondary sewage treatment plant.

The plant influent first passes through bar screens for removal of coarse debris, and is then conveyed by low lift pumps, if required, to a channel leading to rotary mesh screens inside a treatment building.

The effluent from the rotary screens would be dosed with alum and polymer as required for formation of floc. Only polymer would be added to the RDWS flows. The sewage passes through mixers to effect complete blending and flows along a channel leading to the gravity filters. The filter effluent is then conveyed to the aeration tanks.

Flows beyond the capacity of the aeration tanks overflow to a basin for disinfection and discharge to the receiving water. Backwash water could be filter effluent or plant secondary effluent, and should be periodically chlorinated to inhibit slime and algal growth in the filter media. Polymer can also be added to the backwash water to aid in backwash solids settling and to precondition the filter media for the next cycle. Low pressure blowers would provide backwash air. The filter backwash effluent is conveyed to the sludge handling facilities of the sewage treatment plant or can be processed separately on-site (i.e., dewatered).

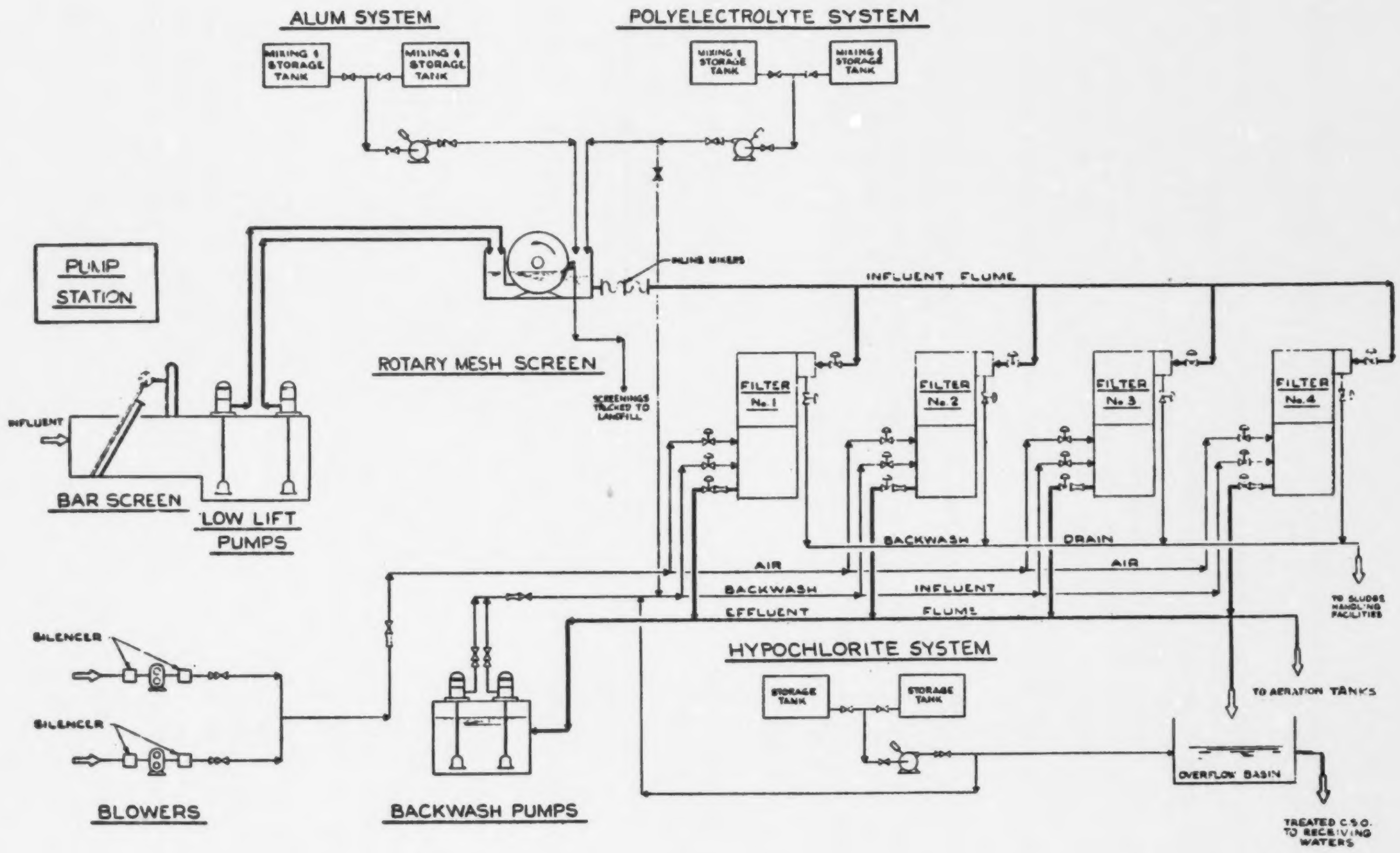

ALUM SYSTEM
MIXING & STORAGE TANK
MIXING & STORAGE TANK
POLYELECTROLYTE SYSTEM
MIXING & STORAGE TANK
MIXING & STORAGE TANK
PUMP STATION
INLINE MIXERS
INFLUENT FLUME
ROTARY MESH SCREEN
SCREENINGS TRUCKED TO LANDFILL
INFLUENT
BAR SCREEN
LOW LIFT PUMPS
FILTER No. 1
FILTER No. 2
FILTER No. 3
FILTER No. 4
BACKWASH
DRAIN
AIR
AIR
BACKWASH
INFLUENT
EFFLUENT
FLUME
TO SLUDGE HANDLING FACILITIES
SILENCER
SILENCER
BLOWERS
BACKWASH PUMPS
HYPOCHLORITE SYSTEM
STORAGE TANK
STORAGE TANK
TO AERATION TANKS
OVERFLOW BASIN
TREATED C.S.O. TO RECEIVING WATERS

FIGURE 13 - DUAL TREATMENT HRF INSTALLATION - PROCESS FLOW DIAGRAM

MODE OF OPERATION

The design should incorporate automated operation, with personnel required only for routine maintenance and periodic delivery of chemicals.

The mode of operation most amenable to automated control is "declining rate filtration," in which the filter flux decreases without mechanical or instrument control from a preset maximum initial value as the filter head loss increases. Filter influent controls would maintain a constant hydraulic head. When the filter head loss reaches a preset value filtration is terminated and a backwash cycle begins. The operation cycles of the filter units are staggered so that the backwashes occur in sequence. Declining rate filtration is not a new operating technique; it is common practice in potable water filtration and has been used for many years for industrial applications.

The filters would operate at different flux rates during dry and wet weather. During dry weather the average flux would be 8-12 gpm/ft^2 (20-30 m^3/hr/m^2). As increased (storm) flow enters the treatment plant each filter will automatically adjust to achieve higher initial flux by sensor regulation of the filter effluent valve. Adequate instrumentation would insure a smooth transition from dry-weather to storm-flow operation.

CONCEPTUAL DUAL-TREATMENT DESIGN

For design purposes, the low lift pumping facility and HRF system have been incorporated into one site. The 25 to 200 mgd systems discussed below cover the range of most potential dual-treatment applications. The designs are based on an average wet weather filtration flux of 16 gpm/ft^2 (40 m^3/hr/m^2). The hydraulic capacities of these facilities should be set at 20 percent greater than the design rates as determined by process considerations to accommodate temporary conditions of elevated flux as during the transition to storm-flow operation with declining rate filtration.

Figures 14 to 18 present general plans and elevations of HRF installations. The treatment systems have the same basic arrangements, the major differences being the size and numbers of the pumping and treatment units. The facilities consist of a pumping station, housing bar screens and variable speed low lift pumps, the head end of the treatment plant, housing the rotary mesh screens, and the main treatment area, containing the HRF units.

In the control building, the first level contains the bar screens, lift pumps, chemical storage area, alum and polymer feed equipment, air blowers and the backwash pumps. Chlorination equipment can be located here or be connected to similar equipment in the secondary treatment area. The upper level of the control building includes the rotary mesh screens, electrical and instrumentation control areas, and space for office, service areas, etc.

Figure 19 shows a typical cross section of the filtration portion of the main treatment area, with the filter units arranged symmetrically along the center line of the filter bay. Sewage flows from the central influent channel into individual receiving chambers or gullets and then to the filters. The effluent channel connects to a reservoir extending the entire width of the filter bay, providing sufficient backwash water storage. The treated effluent then flows by gravity in a channel to the aeration tanks. One or more automated overflow chambers connect with the channel to receive excess filtered CSO which is chlorinated and discharged.

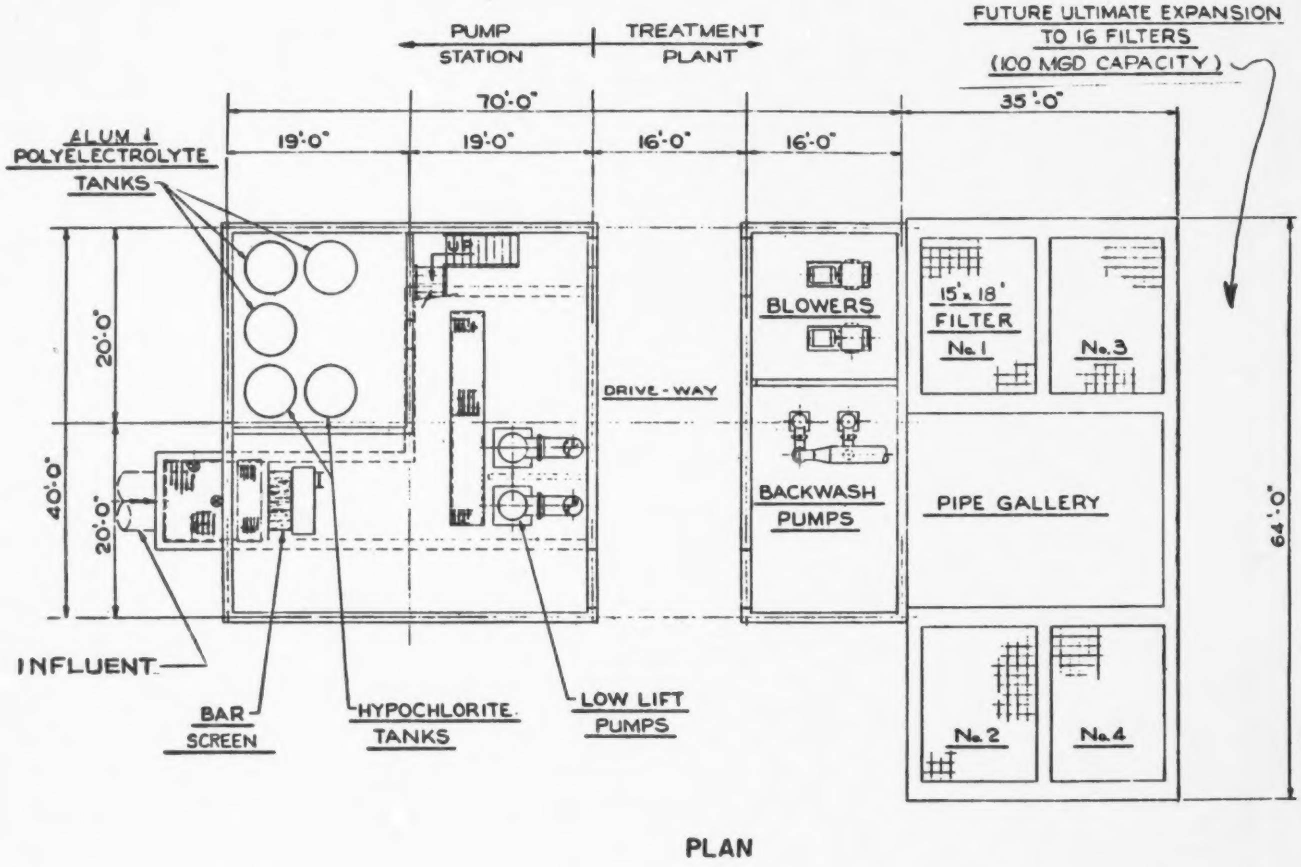

PUMP STATION
TREATMENT PLANT
FUTURE ULTIMATE EXPANSION TO 16 FILTERS (100 MGD CAPACITY)
70'-0"
35'-0"
19'-0"
19'-0"
16'-0"
16'-0"
ALUM & POLYELECTROLYTE TANKS
UP
DRIVE-WAY
BLOWERS
15' x 18' FILTER No. 1
No. 3
20'-0"
40'-0"
20'-0"
BACKWASH PUMPS
PIPE GALLERY
64'-0"
INFLUENT
BAR SCREEN
HYPOCHLORITE TANKS
LOW LIFT PUMPS
No. 2
No. 4
PLAN

FIGURE 14 - DUAL TREATMENT HRF INSTALLATION - 25 MGD CAPACITY

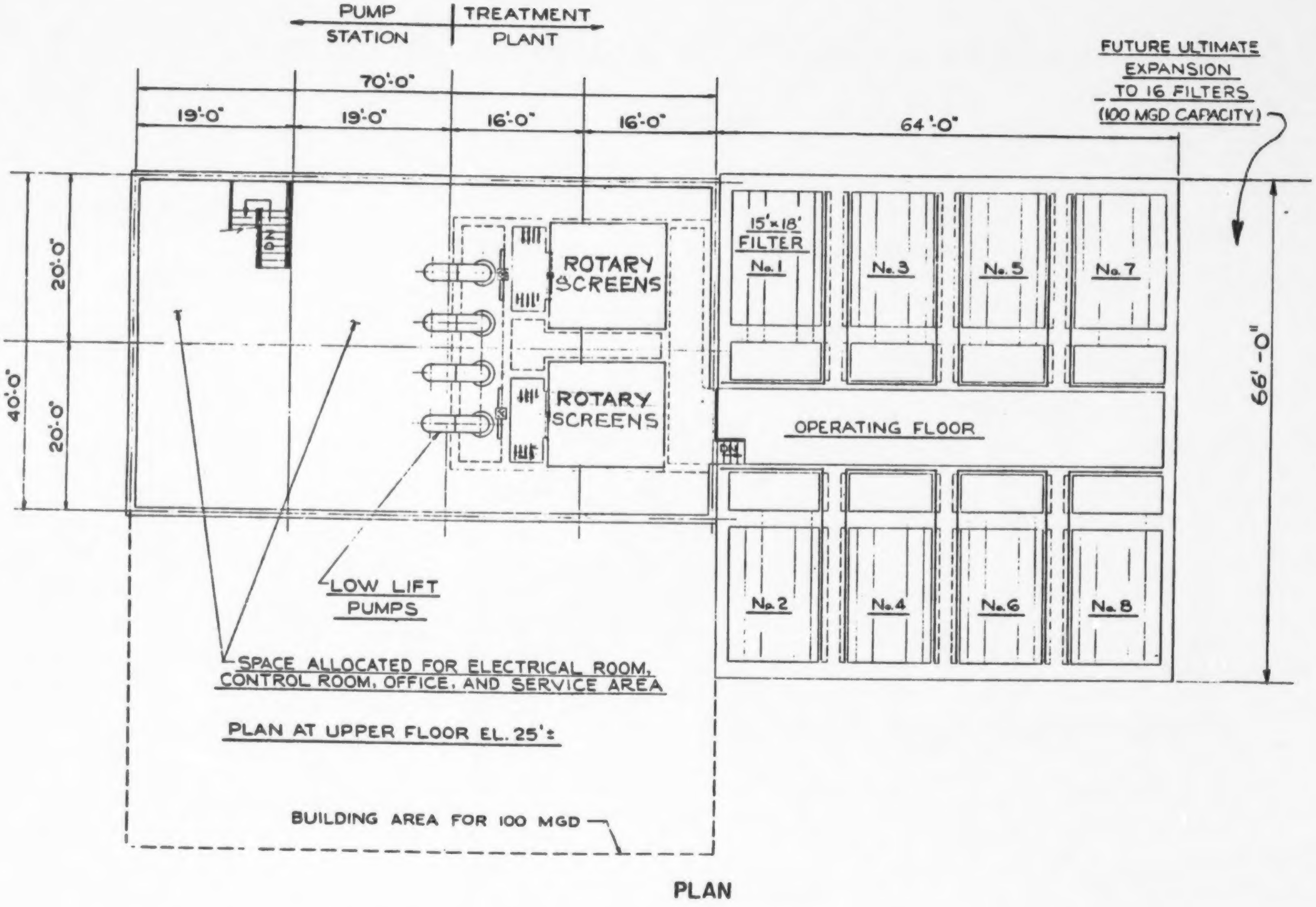
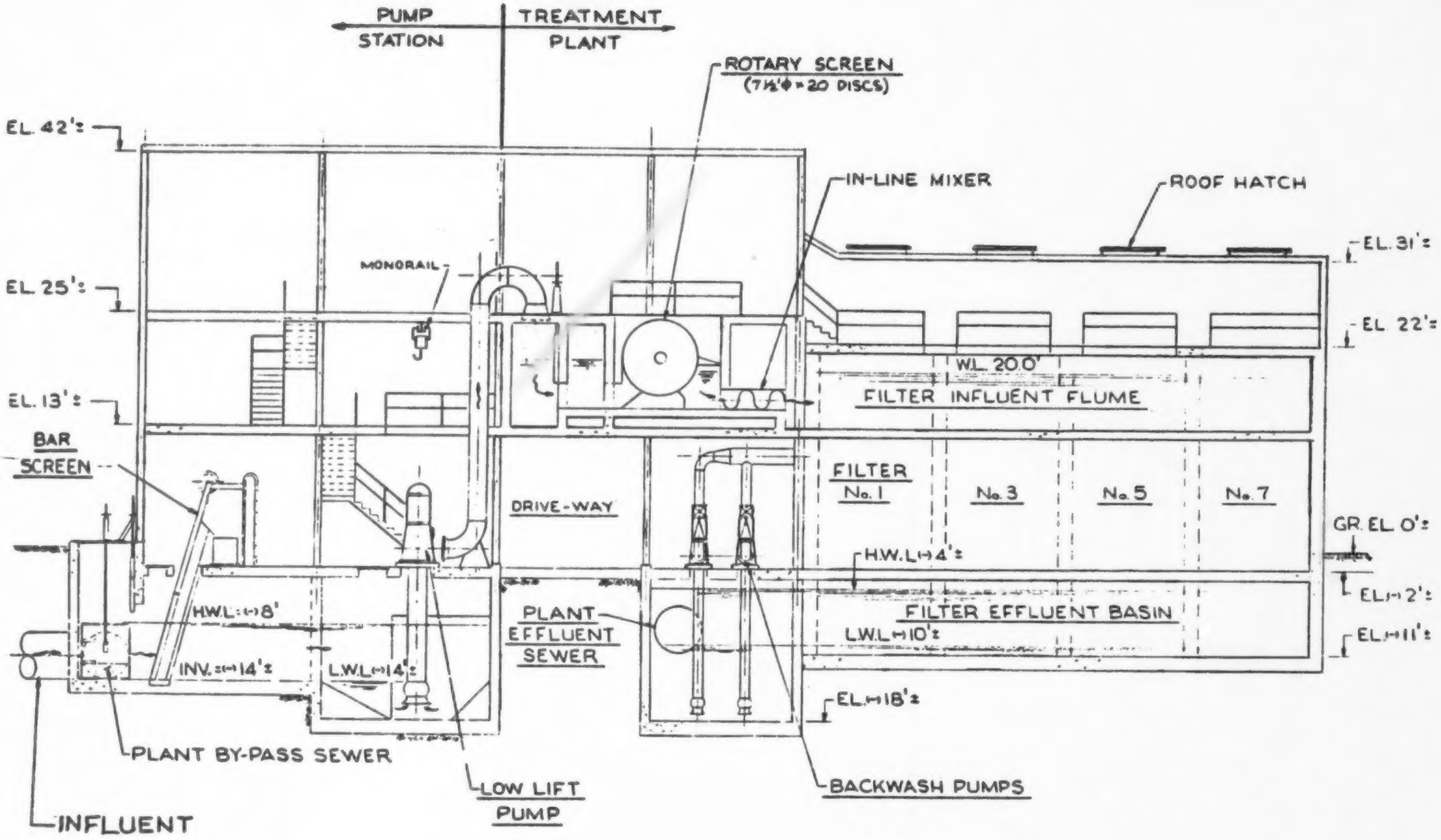
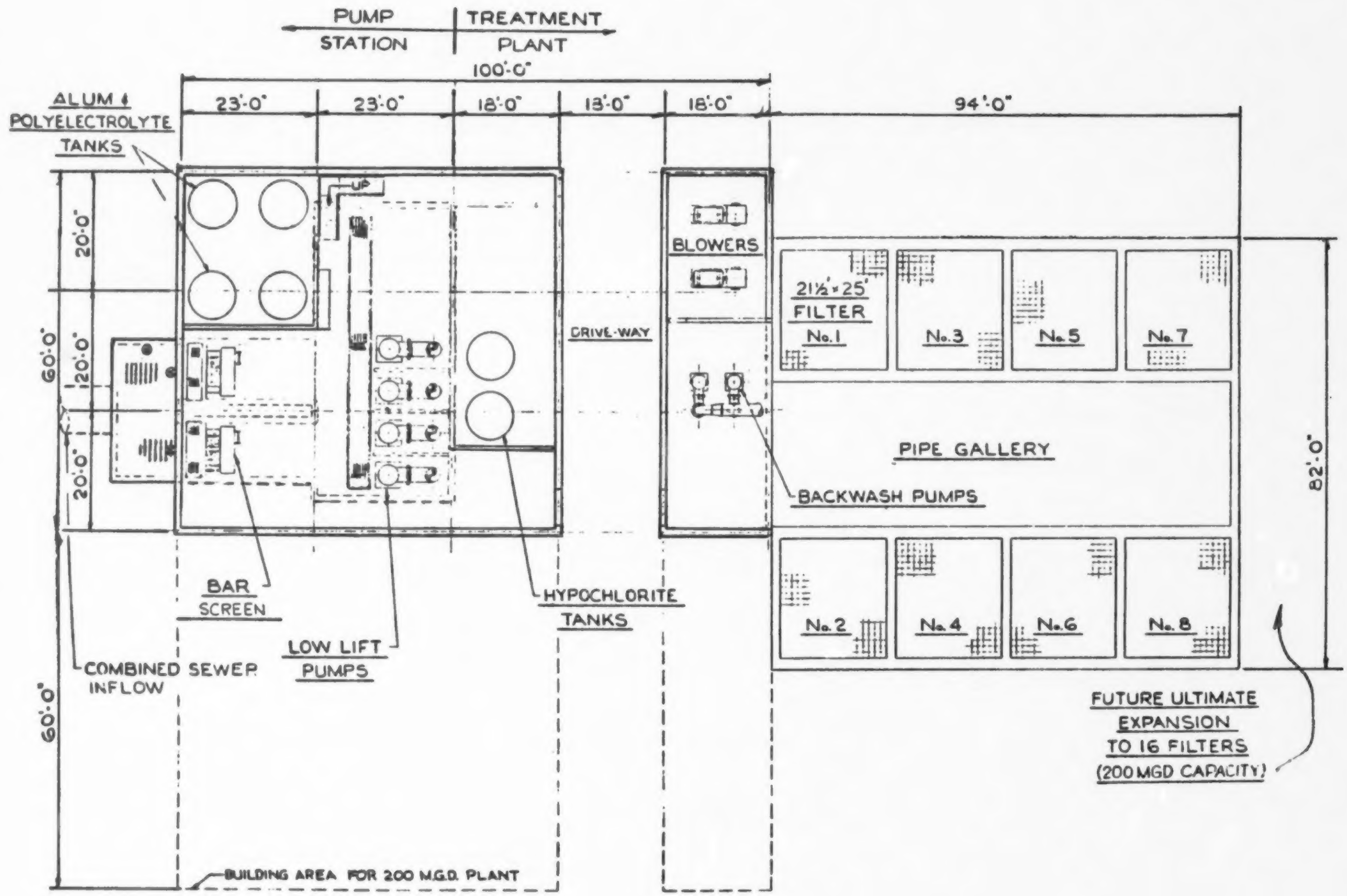

PUMP STATION
TREATMENT PLANT
70'-0"
19'-0"
19'-0"
16'-0"
16'-0"
64'-0"
FUTURE ULTIMATE EXPANSION TO 16 FILTERS (100 MGD CAPACITY)
20'-0"
20'-0"
40'-0"
66'-0"
ROTARY SCREENS
ROTARY SCREENS
15'×18' FILTER
No. 1
No. 3
No. 5
No. 7
OPERATING FLOOR
No. 2
No. 4
No. 6
No. 8
LOW LIFT PUMPS
SPACE ALLOCATED FOR ELECTRICAL ROOM, CONTROL ROOM, OFFICE, AND SERVICE AREA
PLAN AT UPPER FLOOR EL. 25'±
BUILDING AREA FOR 100 MGD
PLAN

FIGURE 15 - DUAL TREATMENT HRF INSTALLATION - 50 MGD CAPACITY


PUMP STATION
TREATMENT PLANT
ROTARY SCREEN (7½'Φ×20 DISCS)
EL. 42'±
IN-LINE MIXER
ROOF HATCH
EL. 31'±
MONORAIL
EL. 25'±
EL. 22'±
WL. 20.0'
FILTER INFLUENT FLUME
EL. 13'±
BAR SCREEN
FILTER No. 1
No. 3
No. 5
No. 7
DRIVE-WAY
GR. EL. 0'±
H.W.L.(-)4'±
EL.(-)2'±
PLANT EFFLUENT SEWER
FILTER EFFLUENT BASIN
H.W.L.(-)8'
L.W.L.(-)10'±
EL.(-)11'±
INV.=(-)14'±
L.W.L.(-)14'±
EL.(-)18'±
PLANT BY-PASS SEWER
LOW LIFT PUMP
BACKWASH PUMPS
INFLUENT

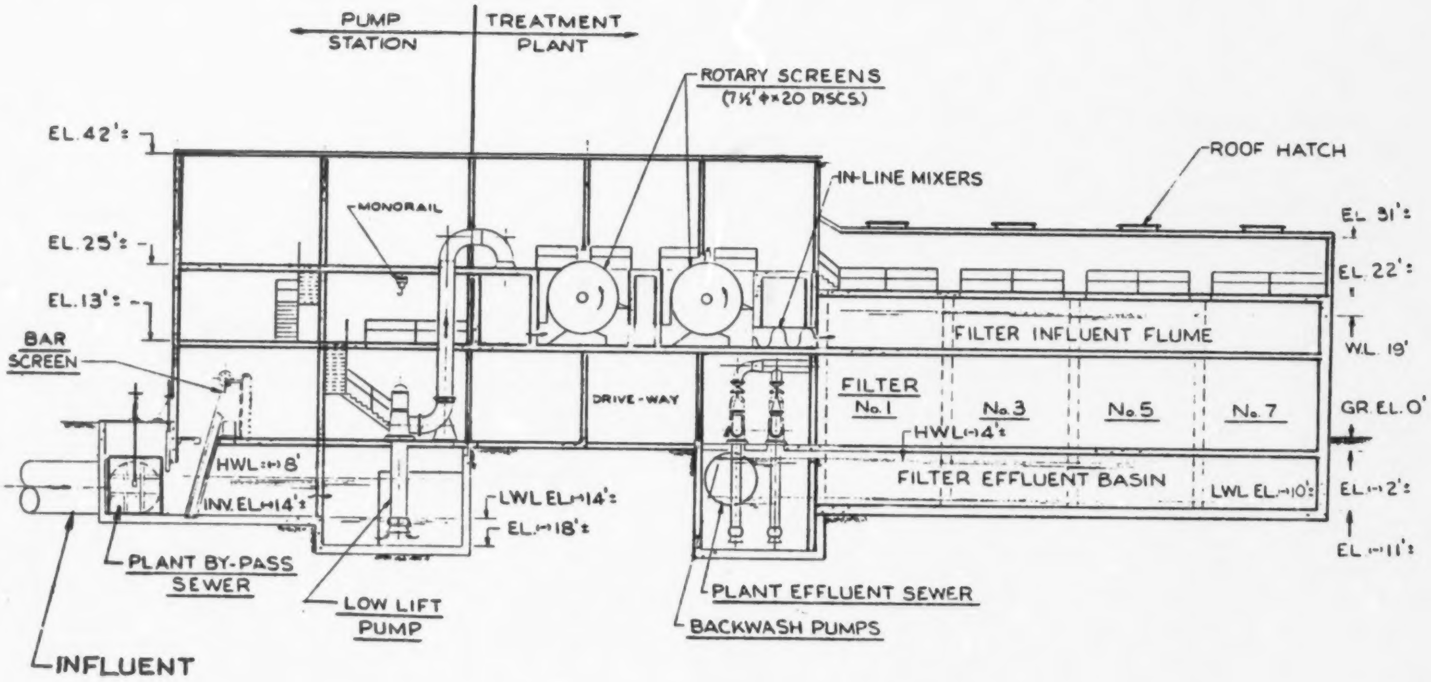
ELEVATION

Figure 16 - Dual treatment HRF installation - 50 MGD capacity


PUMP STATION
TREATMENT PLANT
100'-0"
23'-0"
23'-0"
18'-0"
13'-0"
18'-0"
94'-0"
ALUM & POLYELECTROLYTE TANKS
UP
20'-0"
20'-0"
20'-0"
60'-0"
60'-0"
82'-0"
BLOWERS
21½'×25' FILTER No. 1
No. 3
No. 5
No. 7
No. 2
No. 4
No. 6
No. 8
DRIVE-WAY
PIPE GALLERY
BACKWASH PUMPS
BAR SCREEN
HYPOCHLORITE TANKS
LOW LIFT PUMPS
COMBINED SEWER INFLOW
FUTURE ULTIMATE EXPANSION TO 16 FILTERS (200 MGD CAPACITY)
BUILDING AREA FOR 200 M.G.D. PLANT

PLAN

FIGURE 17 - DUAL TREATMENT HRF INSTALLATION - 100 MGD CAPACITY


PUMP STATION
TREATMENT PLANT
ROTARY SCREENS (7½'φ×20 DISCS.)
ROOF HATCH
IN-LINE MIXERS
EL. 42'±
EL. 25'±
EL. 13'±
MONORAIL
BAR SCREEN
DRIVE-WAY
FILTER INFLUENT FLUME
FILTER No. 1
No. 3
No. 5
No. 7
HWL(-)4'±
FILTER EFFLUENT BASIN
LWL EL.(-)10'±
EL. 31'±
EL. 22'±
WL. 19'
GR. EL. 0'
EL.(-)2'±
EL.(-)11'±
HWL(-)8'
INV. EL.(-)14'±
LWL EL.(-)14'±
EL.(-)18'±
PLANT BY-PASS SEWER
LOW LIFT PUMP
PLANT EFFLUENT SEWER
BACKWASH PUMPS
INFLUENT

ELEVATION

FIGURE 18 - DUAL TREATMENT HRF INSTALLATION - 100 MGD CAPACITY

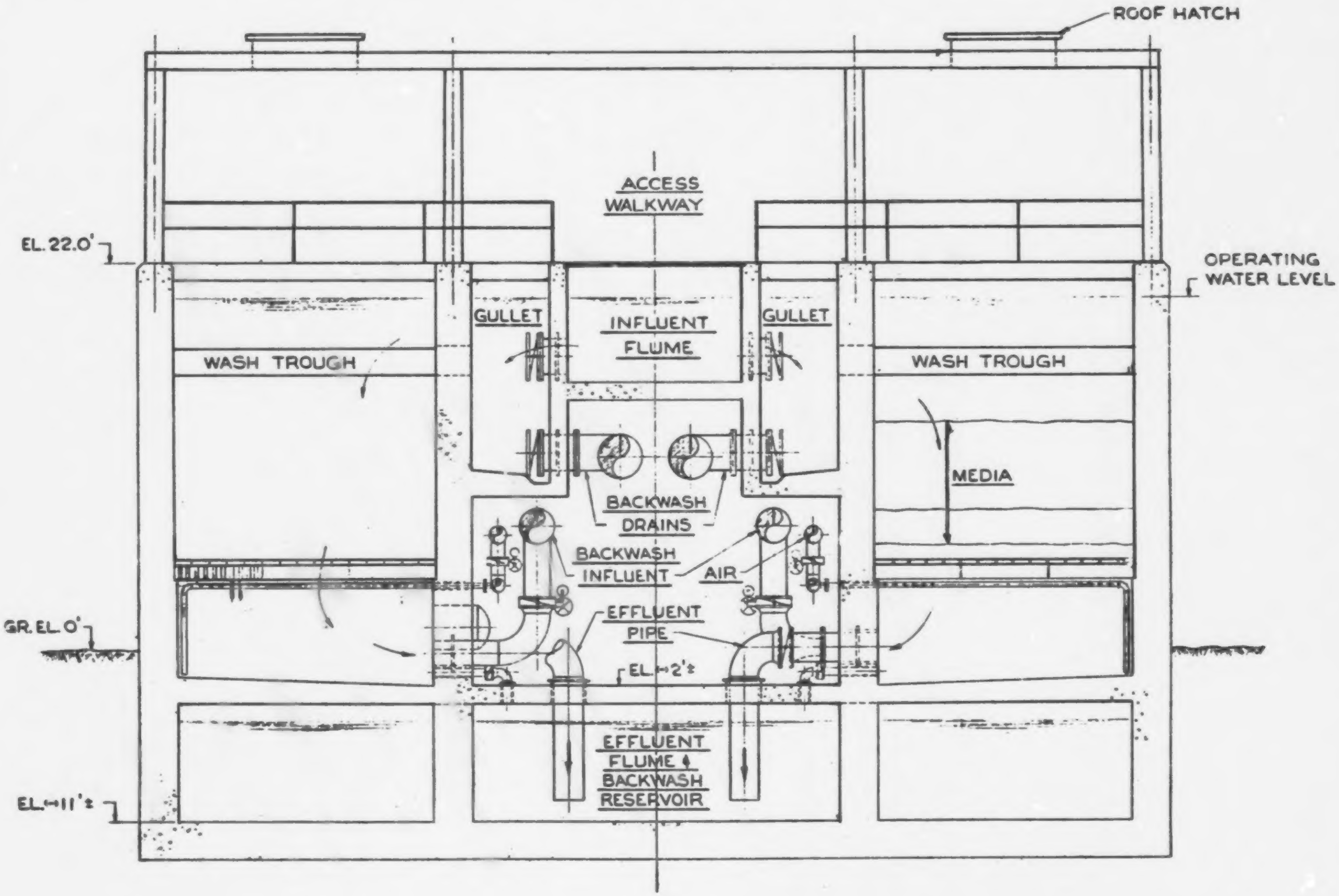

ROOF HATCH
ACCESS WALKWAY
EL. 22.0'
OPERATING WATER LEVEL
GULLET
INFLUENT FLUME
GULLET
WASH TROUGH
WASH TROUGH
MEDIA
BACKWASH DRAINS
BACKWASH INFLUENT
AIR
EFFLUENT PIPE
EL.-2'±
GR. EL. 0'
EFFLUENT FLUME & BACKWASH RESERVOIR
EL.-11'±

FIGURE 19 - DUAL TREATMENT HRF INSTALLATION - TYPICAL FILTER SECTION

SECTION 8

COST ESTIMATES

GENERAL

Estimates of capital and operating costs have been developed for the designs discussed in Section 7 and are divided into two categories: the pumping station and the HRF facility. The filtration plant estimates presented in the summary curves (Figures 20-22) can be used to compare alternate technologies for separate or dual-treatment of CSO during wet weather flow conditions and RDWS during dry weather.

CAPITAL CONSTRUCTION COSTS

Estimated capital costs of dual-treatment filtration facilities are presented for 25 to 200 mgd (94,600-757,000 m^3/day) capacity plants. The total project capital costs are summarized in Table 13. An analysis of cost vs. capacity is shown on Figure 20. Detailed data on capital cost estimates are given in Table 14 based on a design CSO filtration flux of 16 gpm/ft^2 (40 m^3/hr/m^2) and including equipment for alum and polymer addition.

TABLE 13. SUMMARY OF TOTAL PROJECT COSTS

HRF Plant Capacity (mgd)	Total Capital Cost (ENR = 2520)
25	$ 2,731,000
50	4,362,000
1 00	8,111,000
200	13,981,000

Design flux of 16 gpm/ft^2 (40 m^3/hr/m^2)
Project costs include pumping station and treatment plant.
1 mgd = 3,785 m^3/day

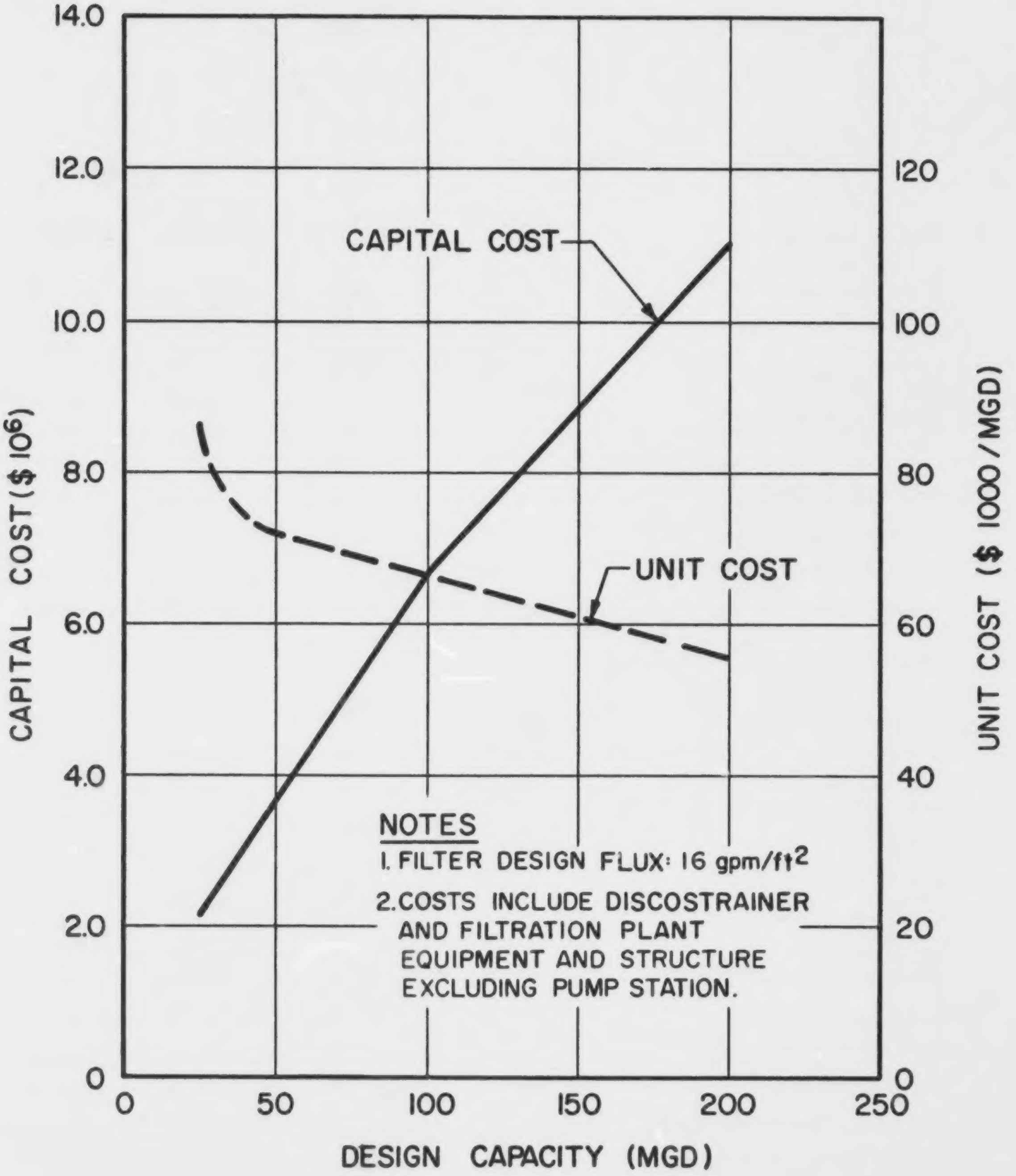


FIGURE 20 - ESTIMATED CAPITAL COST VS DESIGN CAPACITY

TABLE 14. ESTIMATED PROJECT COSTS FOR HRF TREATMENT PLANTS

		25 MGD	50 MGD	100 MGD	200 MGD
I.	PUMPING STATION				
	Excavation and Backfill	$ 7,000	$ 7,000	$ 9,000	$ 18,000
	Reinforced Concrete	66,000	66,000	130,000	260,000
	Building	85,000	85,000	190,000	385,000
	Bar Screen	35,000	35,000	70,000	140,000
	Pump	140,000	240,000	440,000	820,000
	Piping	10,000	20,000	30,000	45,000
	Heating and Ventilating	20,000	25,000	35,000	50,000
	Electrical	70,000	100,000	260,000	565,000
	Plumbing, Lighting, Interior & etc.	35,000	45,000	50,000	100,000
	Sub-total	$ 468,000	$ 623,000	$1,214,000	$2,383,000
	Construction Contingency	56,000	75,000	146,000	286,000
	Sub-total Construction Cost.	$ 524,000	$ 698,000	$1,360,000	$2,669,000
	Engineering & Administration	52,000	70,000	136,000	267,000
	Project Sub-total, Conveyance Portion	$ 576,000	$ 768,000	$1,496,000	$2,936,000
II.	FILTRATION FACILITY				
	Excavation and Backfill	$ 19,000	$ 24,000	$ 35,000	$ 90,000
	Reinforced Concrete	345,000	628,000	1,225,000	1,915,000
	Building	160,000	210,000	430,000	805,000
	Discostrainer	375,000	750,000	1,500,000	3,000,000
	Static Mixers	20,000	40,000	50,000	100,000
	Filter Media and Filter Bottom	50,000	100,000	205,000	410,000
	Filter Backwash Pump	35,000	35,000	60,000	65,000
	Air Blower	35,000	35,000	60,000	65,000
	Piping	275,000	540,000	1,060,000	1,395,000
	Polyelectrolyte	35,000	35,000	50,000	85,000
	Alum Feed	35.000	35.000	45,000	50.000
	Chlorination Equipment	50,000	50,000	80,000	110,000
	Heating and Ventilating	25,000	30,000	50,000	70,000
	Electrical	90,000	105,000	155,000	225,000
	Instrumentation	120,000	205,000	225,000	410,000
	Plumbing, Lighting, Interior & etc.	80,000	95,000	140,000	170,000
	Sub-total	$ 1,749,000	$ 2,917,000	$ 5,370,000	$ 8,965,000
	Construction Contingency (12%)	210,000	350,000	644,000	1,076,000
	Sub-total Construction	$ 1,959,000	$ 3,267,000	$ 6,014,000	$ 10,041,000
	Engineering & Administration (10%)	196,000	327,000	601,000	1,004,000
	Project Sub-total - Treatment Portion	$ 2,155,000	$ 3,594,000	$ 6,615,000	$ 11,045,000
III.	TOTAL PROJECT COSTS	$ 2,731,000	$ 4,362,000	$ 8,111,000	$ 13,981,000
IV.	PROJECT COST/MGD CAPACITY	$ 109,240	$ 87,240	$ 81,110	$ 69,905

NOTE: 16 gpm/ft^2 (40 m^3/hr/m^2) Filtration Flux
Engineering News Record Construction Cost Index = 2520

Capital cost estimates for the treatment facilities include: the cost of equipment, installation and construction costs and a 12 percent allowance for contingencies, plus a 10 percent allowance for engineering and administration for the proposed construction. The cost estimates do not include the cost of land, backwash sludge handling and interest during construction.

TOTAL ANNUAL COSTS

Table 15 and Figure 21 present summaries of total estimated annual costs for HRF plants of 25 through 200 mgd capacities. The annual costs are in categories of separate CSO treatment plants operating only during the estimated 450 hours of CSO per year and dual-treatment plants operating 8760 hours per year (365 days including 450 hours of CSO filtration). The costs include amortization, operation and maintenance.

TABLE 15. SUMMARY OF TOTAL ANNUAL COSTS

HRF Plant Capacity (mgd)	Annual Cost (450 hr/yr) CSO Treatment Plant	Annual Cost (8760 hr/yr) Dual-Treatment Plant
25	$ 238,050	$ 396,450
50	382,350	600,100
100	693,200	1,053,600
200	1,175,900	1,794,050

Design flux of 16 gpm/ft^2 (40 m^3/hr/m^2) for CSO treatment and 8 gpm/ft^2 (20 m^3/hr/m^2) for RDWS treatment.
1 mgd = 3,785 m^3/day

Table 16 gives breakdowns of these cost data. These costs are based upon the following assumptions:

a. Interest at six percent for 25 years.

b. Maintenance at dual treatment plants being three percent of mechanical equipment cost, two percent of electrical and instrumentation cost and one percent of piping cost. For CSO treatment plants, maintenance costs are set at 67 percent of the costs at the same size dual treatment plants except for equal piping maintenance.

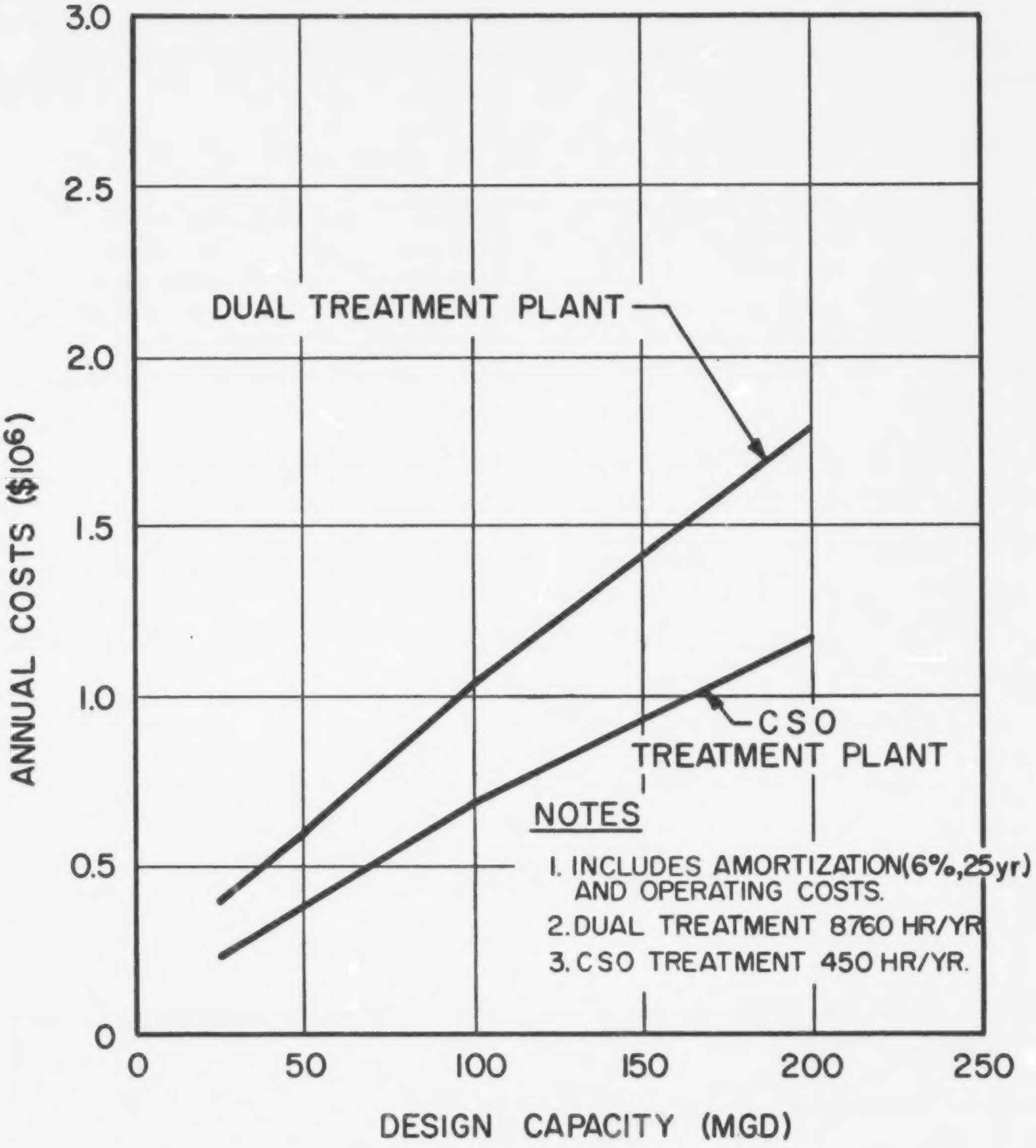


FIGURE 21 - TOTAL ANNUAL COST VS DESIGN CAPACITY

TABLE 16. ESTIMATED ANNUAL COSTS FOR HRF TREATMENT PLANTS

	25 MGD		50 MGD		100 MGD		200 MGD	
	CSO Treatment	Dual Treatment	CSO Treatment	Dual Treatment	CSO Treatment	Dual Treatment	CSO Treatment	Dual Treatment
AMORTIZATION								
6 percent Interest Rate for 25 years	$ 173,000	$ 173,000	$ 287,000	$ 287,000	$ 531,000	$ 531,000	$ 896,000	$ 896,000
OPERATING COSTS								
Labor (Includes Overhead & Benefits)	$ 30,000	$ 100,000	$ 30,000	$ 100,000	$ 37,000	$ 125,000	$ 45,000	$ 150,000
Maintenance								
Mechanical Equipment	$ 12,400	$ 18,500	$ 21,500	$ 32,100	$ 41,300	$ 61,500	$ 78,000	$ 116,500
Electrical and Instrumentation	$ 2,800	$ 4,200	$ 4,150	$ 6,200	$ 5,100	$ 7,600	$ 8,500	$ 12,750
Piping	$ 2,750	$ 2,750	$ 5,400	$ 5,400	$ 10,600	$ 10,600	$ 14,000	$ 14,000
Utilities								
Electric ($.05/kwh)	$ 2,000	$ 37,000	$ 2,600	$ 47,400	$ 4,700	$ 73,900	$ 7,400	$ 116,800
Chemicals								
Chlorine (16 mg/l)	$ 5,900	$ 5,900	$ 11,800	$ 11,800	$ 23,600	$ 23,600	$ 47.200	$ 47,200
Coagulant (20 mg/l)	5,100	5,100	10,200	10,200	20,400	20,400	40,800	40,800
Polymer (0.5 mg/l)	4,800	50,000	9,700	100,000	19,500	200,000	39,000	400,000
Operating Costs Sub-total	$ 65.050	$ 223,450	$ 95,350	$ 313,100	$ 162,200	$ 522,600	$ 279,900	$ 898,050
Total Annual Costs	$ 238,050	$ 396,450	$ 382,350	$ 600,100	$ 693,200	$ 1,053,600	$ 1,175,900	$ 1,794,050
Annual Cost/MG Treated	$ 508	$ 83	$ 408	$ 63	$ 370	$ 55	$ 314	$ 47

Based on - CSO Treatment Operating 450 hrs/y
Dual Treatment Operating 8760 hrs/y

c. Labor at $25,000 per man year, including overhead and benefits.

d. Filter flux averaging 16 gpm/ft^2 (40 m^3/hr/m^2) during CSO treatment and 8 gpm/ft^2 (20 m^3/hr/m^2) during RDWS treatment.

e. Chemical applications of alum (20 mg/l) and polymer (0.5 mg/l) to the filter influent during CSO treatment and polymer (0.5 mg/l) during RDWS treatment.

f. After filtration chlorination (10 mg/l) of only CSO and periodic backwashes.

g. Unit costs of chemicals are:

Polymer-$2.50/lb ($5.50/kg) (cost may vary greatly by type used)

Chlorine - 15 ¢/lb (33¢/kg)

Alum - 6.5¢/lb (14¢/kg)

The HRF plants have been sized according to CSO flux capacity. Dual-treatment plants, operating mostly during dry weather, will be operating at an average of one-third to one-half the filtration flux of storm flow conditions. The CSO treatment plants, idle through most of the year, will have much higher total annual costs per unit of treatment (dollars per million gallons) than the dual-treatment plants which operate full-time. From the above assumptions, it can be calculated that the annual cost per million gallons treated would range from $508 down to $314 for CSO plants of 25 to 200 mgd capacity. For dual-treatment plants, these unit costs would be from $83 to $47 over the same capacity range (See Table 16).

Figure 22 presents a comparison of CSO operating cost-benefits for treatment with doses of chemical flocculant aids (20 mg/l alum and 0.5 mg/l polymer) and treatment without chemical additions. Assumptions, based on testing results, are: influent SS 200 mg/l; percent system SS removals 70 percent with alum and polymer addition, 62 percent without chemicals. Operation costs per ton of SS removed from the storm water decrease dramatically with plant size increase from 25 to 50 mgd (94,600 to 189,000 m^3/day) and show a slower but significant decrease with plant sizes up to 200 mgd (757,000 m^3/day). Treatment without chemicals has an increasing advantage in cost benefits for all plants of 25-200 mgd capacity. This indicates that the extra costs with use of chemicals outweighs the benefit of

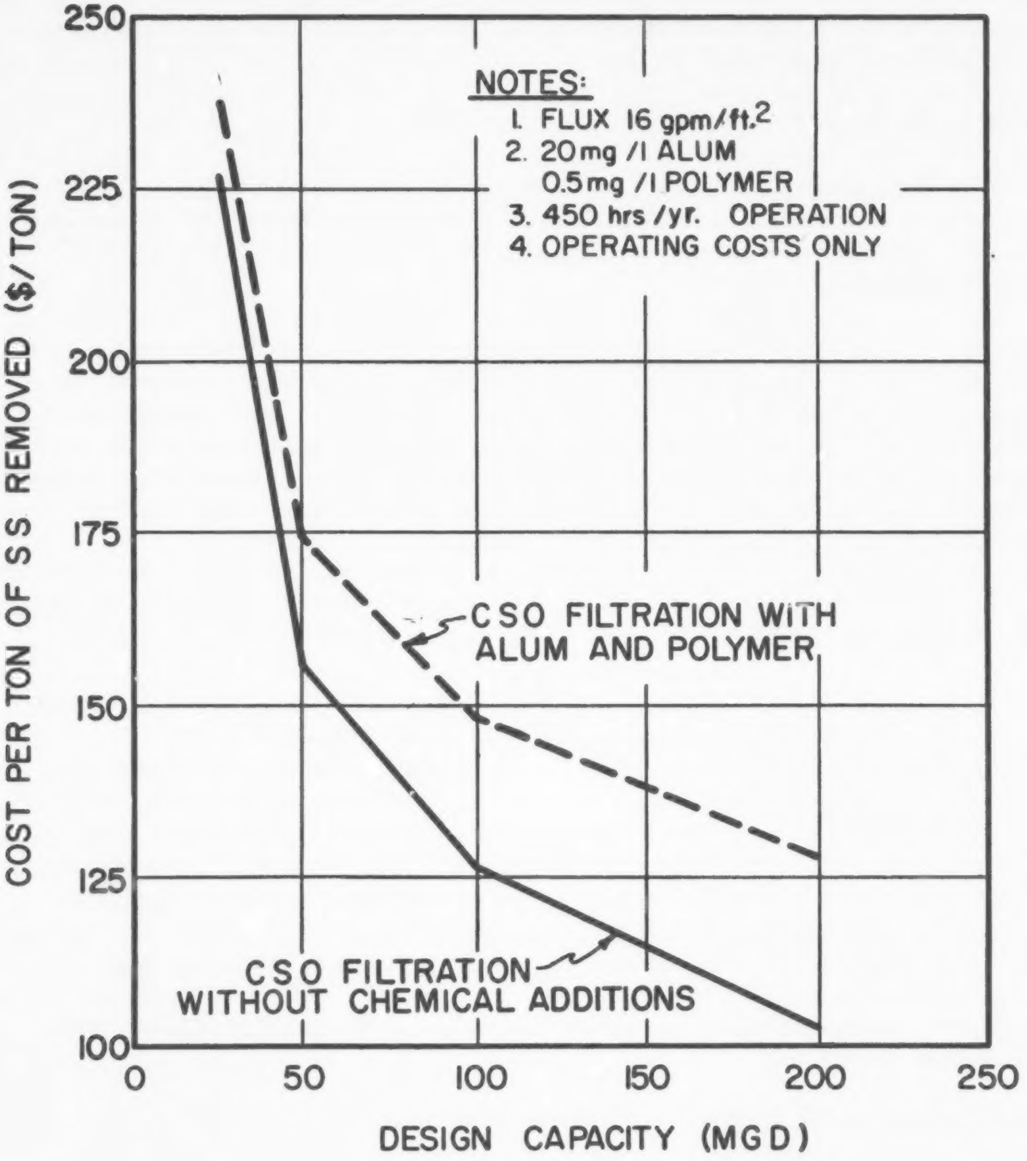


FIGURE 22 - OPERATING COST - BENEFITS, CSO TREATMENT

extra treatment received unless environmental regulations require effluent concentrations obtainable only by the use of chemical additives. The operating costs for 25 mgd plants are inflated by the fact that labor costs are the same as those for plants of 50 mgd capacity and at larger plants reflect the economics of scale.

DUAL-TREATMENT SYSTEM COMPARISONS

HRF in dual functions could increase the capacity of an overloaded secondary sewage treatment plant. During dry weather HRF could be used to improve the primary effluent, and to treat CSO during storm flow conditions.

Tables 17 and 18 present comparisons of HRF plants vs primary clarification in capital and operating costs and area requirements for 25 to 200 mgd (94,600-757,000 m^3/day) capacities. HRF facilities include rotary screens and filters while the clarification facilities include grit chambers and primary clarifiers. The comparisons exclude cost of land acquisition,pumping stations, bar screens or chemical additions and assume equivalent (60 percent) SS removals at a 16 gpm/ft^2 (40 $m^3/hr/m^2$) RDWS flux and a 700 gpd/ft^2 (28.6 $m^3/day/m^2$) clarifier overflow rate. Bases for operating costs are as given previously in the discussion of annual costs except amortization is excluded.

The compactness of HRF is immediately evident from Table 18. Land requirements for the HRF units are only 5 to 7 percent of that necessary for primary clarifiers of the same capacity. On Table 17, it should be noted that the rotary screens are much more costly than the grit chambers commonly used ahead of primary clarifiers; the screen estimates were based on the costs of the largest Discostrainer units now available. Since large scale treatment of raw sewage is a relatively new application of this type of screen, costs of units designed for 25 to 200 mgd size facilities should be considerably lower than those indicated. The HRF units themselves have a significant cost advantage over primary clarifiers; this cost advantage increases with treatment capacity.

CSO TREATMENT SYSTEM COMPARISONS

Table 19 presents a comparison of HRF with several alternate CSO treatment systems in terms of SS removal efficiency, capital and operating costs, area requirements and operating cost-benefits for a 25 mgd (94,600 m^3/day) facility. The data for the alternate systems was taken primarily from two recent comprehensive studies of CSO treatment technology (12)

TABLE 17. DUAL-TREATMENT SYSTEM COST COMPARISONS

	Capital Cost ($1,000)*						Operating Cost ($1,000)*	
	HRF			Primary Clarification				
Design Capacity (mgd)	Screening	Filtration	Total	Grit Removal	Clarifiers	Total	HRF	Primary Clarification
25	375	1,234	1,609	102	1,619	1,721	163	136
50	750	2,007	2,757	130	3,032	3,162	191	166
100	1,500	3,645	5,145	250	5,617	5,867	279	244
200	3,000	5,620	8,620	481	8,885	9,366	410	350

* Costs do not include acquisition of land, pumping stations, bar screens, chemical feeding and amortization.

TABLE 18. DUAL-TREATMENT SYSTEM AREA COMPARISON

	Treatment Area (ft^2) [1 ft^2 = 0.0929 m^2]	
Design Capacity (mgd)	HRF	Primary Clarifiers
25	3,520	55,000
50	5,500	100,000
100	10,250	196,000
200	19,000	393,000

TABLE 19. CSO TREATMENT SYSTEM COMPARISONS

Treatment Process	% Removal SS* (Design)	% Removal SS* (Range)	25 mgd Capacity Facility: Capital Costs	Operating Costs	Treatment Area (ft^2)	Unit Capital Cost (per 1000 gal)	Cost-Benefit Index ($ Operating per 1000 gal/% SS removal)
HRF System with Discostrainers	70	(50-80)	$2,155,000	$35,000	3,520	$86.	$0.40
Flocculation=Sedimentation with Grit Chamber	68		2,450,000	70,000	42,000	98.	0.82
Microstrainers (Horizontal Shaft Screens)	70	(50-90)	1,180,000	30,000	2,500	47.	0.34
Dissolved Air Flotation with Drum Screens	70	(45-85)	2,540,000	61,000	23,000	102.	0.70
Swirl Concentrator with Swirl Degritter	40	(40-60)	225,000	15,800	1,200	9.0	0.32
Vertical Shaft Rotary Screens (Drum Screens)	40	(30-55)	1,000,000	23,000	2,250	40.	0.46
High Gradient Magnetic Separation System	95	(95-98)	2,690,000	69,400	12,000	108.	0.59

NOTE: Costs exclude diversion structures, pumping stations, bar screens or sludge handling but include chlorination for disinfection.
Costs assume CSO treatment operating 120 hrs/yr (30 CSO events).
Engineering News Record Construction Cost Index = 2520.

* The percent SS removal values were obtained from reference 12. The design values were those determined for comparing the operating cost-benefits of the treatment processes.

and costs (13), supplemented by pilot plant studies of individual treatment systems (7, 8, 14, 15, 16).

The comparison shows a wide range of costs, area requirements and treatment efficiencies. Each system has inherent advantages and disadvantages for specific applications. The swirl concentrator is easily the least expensive and most compact system but it is adapted more for removal of the heavier suspended solids fraction rather than total suspended solids. High gradient magnetic separation has only recently been applied to CSO treatment in tests with no more than 1 gpm (0.063 l/s) process flow (16). Flocculation-sedimentation is a well proven system for treatment of many types of wastewater but has great land requirements. Dissolved air flotation and microstraining have proven effective in other wastewater treatment applications and pilot plant scale testing has shown them to be competitive with HRF in CSO treatment.

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APPENDICES

TABLE A-1

HIGH RATE FILTRATION STUDY

CSO Testing Averages

				chem. feed		Suspended Solids						BOD						COD					
date 1976	storm no.	test length (hr)	flux rate gpm/ft^2	alum mg/l	poly mg/l	Pi mg/l	Fi mg/l	Fe mg/l	screen %rem	filter %rem	total %rem	Pi mg/l	Fi mg/l	Fe mg/l	screen %rem	filter %rem	total %rem	Pi mg/l	Fi mg/l	Fe mg/l	screen %rem	filter %rem	total %rem
5-11	S-4A	1.0	16	0	0	249	184	68	26	63	73	174	170	128	2	25	27	448	420	252	6	40	44
5-11	S-4B	3.0	16	0	0	112	105	30	6	71	73	140	132	98	6	26	30	285	297	192	-	35	-
5-17	S-5	1.0	16	0	0	306	270	112	12	59	63	258	258	174	0	33	33	567	527	313	7	41	45
5-21	S-6	1.0	16	0	0	399	379	106	5	72	73	232	259	123	-	53	-	598	591	265	1	55	56
6-1	S-7	1.5	16	0	0	266	261	78	2	70	71	216	228	173	-	24	-	500	474	285	5	40	43
6-29	S-8	1.75	16	0	1.0	161	172	25	-	85	-	129	132	95	-	28	-	263	271	108	-	60	-
9-26	S-9	3.0	16	0	0	152	126	62	17	51	59	137	126	91	8	27	34	318	226	161	29	29	49
10-20	S-10	5.5	16	0	0	189	149	60	21	60	68	223	229	-	-	-	-	382	350	251	8	28	34
10-24	S-11	6.0	16	0	0.5	97	94	49	3	48	50	143	119	79	17	34	45	227	205	132	10	36	42
10-31	S-12	4.0	16	15	0.5	133	122	57	8	53	57	79	67	49	15	27	38	227	190	98	16	48	57
12-7	S-13	6.5	16	0	1.0	296	263	74	11	72	75	142	139	90	2	32	33	384	385	187	-	51	51

Note:
- Storms nos. S4-1 through 7 were tested with the rotostrainer effluent flowing directly into the filters.
- Storm no. 8 was tested with the rotostrainer effluent flowing into a well mixed storage tank prior to the filters, therefore there is no direct correlation between the Pi and Fi samples for this storm.
- Storms nos. 9 and 10 conducted with a 60 mesh screen on the discostrainer, all subsequent tests with a 40 mesh screen on the discostrainer and effluent directly onto the filter.
- Storm no. 10 - BOD effluent samples inadvertently discarded.
- Storm no. 11 aborted after 6 hours due to insufficient storm flow to the plant.
- Storm no. 12 aborted after 3 ½ hours due to insufficient storm flow to the plant.

Pi - Plant Influent; Fi - Filter Influent; Fe - Filter Effluent.

TABLE A-1 (continued)
HIGH RATE FILTRATION STUDY
CSO Testing Averages

				chem feed		Suspended Solids						BOD						COD					
date 1977	storm no.	test length (hr)	flux rate gpm/ft^2	alum mg/l	poly mg/l	Pi mg/l	Fi mg/l	Fe mg/l	screen %rem	filter %rem	total %rem	Pi mg/l	Fi mg/l	Fe mg/l	screen %rem	filter %rem	total %rem	Pi mg/l	Fi mg/l	Fe mg/l	screen %rem	filter %rem	total %rem
3-22	S-14	3.0	16	35	2	185	192	58	-	70	-	107	97	53	2	45	50	293	312	136	-	56	-
4-2	S-15	8.0	16	0	0	198	172	87	13	49	56	157	134	99	23	26	37	344	267	170	22	36	51
4-4	S-16	4.0	16	17	1.3	147	126	31	14	75	79	91	90	58	1	36	36	260	223	125	14	44	52
6-6	S-17	6.0	20	0	1.4	276	248	110	10	56	60	140	171	112	-	35	-	443	434	272	2	37	39
6-9	S-18	10.0	16	15	1	174	158	67	9	58	61	212	192	106	9	45	50	380	280	182	26	35	52

Note: - Storm S-15 aborted after 8 hours due to insufficient storm flow to the plant.
- Storm S-16 aborted after 4 hours due to broken influent pipe.
- Storms S17-18 declining rate filtration; initial flux rate 24 gpm/ft^2.

Pi - Plant Influent; Fi - Filter Influent; Fe - Filter Effluent.

TABLE NO. A-2

RDWS TESTING

FILTER RUN RESULTS

Run No.	Duration Hrs.	Flux gpm/ft^2	Chemical Feed mg/l		S.S. mg/l			S.S. % Rem.		B.O.D. mg/l			B.O.D. % Removal		C.O.D. mg/l			C.O.D. % Removal	
			Poly	Alum	Plant Inf.	Fi	Fe	Tot.	Filter	Plant Infl.	Fi	Fe	Tot.	Filter	Plant Inf.	Fi	Fe	Tot.	Filter
D 1	2.5	8	0	0	157	129	51	68	60	300	290	240	20	17	-	-	-	-	-
D 2	6.0	8	0	0	-	122	41	-	66	-	230	-	-	-	-	-	-	-	-
D 3	6.0	8	0	0	125	120	36	71	70	215	190	70	67	63	340	285	235	30	18
D 4	6.7	8	0	0	-	144	38	-	74	-	190	120	-	37	-	255	155	-	39
D 5	4.0	12	0.5	0	-	183	57	-	69	-	240	165	-	31	-	-	-	-	-
D 6	6.0	12	0.5	0	-	118	38	-	68	-	155	85	-	45	-	300	155	-	48
D 7	5.0	12	0.5	0	-	169	54	-	68	-	170	115	-	32	-	-	-	-	-
D 8	4.0	12	0.5	0	-	181	72	-	60	-	215	150	-	30	-	340	305	-	20
D 9	4.0	12	0.5	0	-	145	44	-	70	-	120	70	-	42	-	-	-	-	-
D 10	8.0	12	0.5	0	-	64	15	-	77	-	70	25	-	64	-	170	80	-	53
D 11	5.0	12	0.5	0	-	104	26	-	75	-	90	40	-	56	-	-	-	-	-
D 12	6.0	12	0.5	0	-	103	52	-	50	-	100	50	-	50	-	250	155	-	38
D 13	7.0	12	0.5	0	-	51	15	-	71	-	55	30	-	45	-	-	-	-	-
D 14	4.0	12	0.5	0	-	134	41	-	69	-	180	130	-	28	-	-	-	-	-
D 15	6.0	12	0.5	10	113	147	59	-	60	150	145	110	27	24	330	315	190	42	40
D 16	6.0	12	0.5	10	-	128	32	-	75	-	115	80	-	30	-	-	-	-	-
D 17	8.0	12	0.5	10	-	159	56	-	65	-	185	140	-	24	-	-	-	-	-
D 18	8.0	12	0.5	10	124	168	73	-	57	130	130	100	38	23	-	-	-	-	-
D 19	8.0	12	0.5	10	170	136	45	78	67	150	130	115	33	12	320	305	210	36	31
D 20	4.0	16	0.5	10	-	156	71	-	54	-	220	150	-	32	-	-	-	-	-
D 21	6.0	16	0.5	10	179	194	85	-	56	185	175	125	32	29	310	350	255	25	27
D 22	8.0	12	0	25	-	116	37	-	68	-	130	110	-	15	-	295	165	-	44
D 23	4.0	16	0	19	232	193	81	65	58	280	230	205	27	11	575	485	330	43	32
D 24	6.0	12	1.0	0	134	167	75	-	55	195	170	140	23	18	425	395	285	33	28
D 25	4.0	16	0.5	0	148	121	43	71	64	134	119	88	34	26	325	268	181	44	32
D 26	8.0	12	0	0	131	101	39	70	61	183	174	108	41	38	340	270	181	47	33
D 27	3.0	16	0.5	30	175	152	30	83	80	195	171	121	38	29	351	315	197	44	34
D 28	6.0	16	5	15	177	143	69	61	52	164	147	134	18	9	398	345	268	33	22
D 29	5.0	12	1.0	10	164	146	56	66	62	163	158	101	38	36	331	303	209	37	31

NOTE: Pi-Plant Influent, Fi - Filter influent, Fe-Filter effluent

D-29 duration actually 7.5 hours, but solids broke through the filter after 5 hours.

TABLE NO. A-3

HIGH RATE FILTRATION STUDY

FILTER PERFORMANCE-CSO

Run No.	Flux Rate (gpm/ft2)	Poly Feed (mg/1)	Alum Feed (mg/1)	Terminal Head Loss (ft)	Length of Run (hr)	Total Volume Filtered (Gal.)	Backwash Water			Air		Suspended Solids Mass Balance Analysis			
							Length (min.)	Total Volume (Gal.)	% Total Water Filtered	Rate (scfm/ft2)	Length (min.)	Total S.S. Influent (lbs)	Total S.S. Effluent (lbs)	Calculated Removed in Column (lbs)	Recovered in Backwash (lbs)
S-4A	16	0	0	-	1.0	4,320	20	2,450	57			5.5	2.0	3.5	2.2
S-4B	16	0	0	10.5	3.0	12,960	17	2,000	15			8.0	2.3	5.7	3.0
S-5	16	0	0	13.8	1.0	4,320	20	2,450	57			11.5	4.8	6.7	5.5
S-6	16	0	0	13.8	1.0	4,320						6.7	1.9	4.8	
S-7	16	0	0	6.6	1.5	6,480						6.9	2.1	4.8	
S-8	16	1.0	0	10.5	1.7	7,340						9.6	1.4	8.2	
S-9	16	0	0	4.3	3.0	12,960	12	1,620	12.5	5.0	6	14.5	6.7	7.8	6.5
S-10	16	0	0	12.1	5.5	23,760	12	1,620	6.8	5.0	6	29.5	11.9	17.6	18.1
S-11	16	0.5	0	7.5	6.0	25,920	10	1,350	5.2	5.0	6	20.3	10.6	9.7	10.1
S-12	16	0.5	15	7.5	4.0	17,280	10	1,350	7.8	5.0	6	17.6	7.3	10.3	12.7
S-13	16	1.0	0	10.5	6.5	28,080	12	1,620	5.7	5.0	2	62.3	19.9	42.4	32.0
S-14	16	2	35	10.5	3.0	12,960	6	820	6.3	5.0	2	20.7	6.3	14.4	10.1
S-15	16	0	0	10.5	8.0	34,560	6	820	2.4	5.0	2	49.5	25.1	24.4	25.1
S-16	16	1.5	17	8.5	4.0	17,280	6	820	4.7	5.0	2	18.2	4.5	13.7	12.6
S-17	20	1.5	0	8.0	6.0	32,400	10	1,350	4.1	5.0	5	28.7	12.7	16.0	8.6
S-18	16	1.0	15	8.0	10.0	43,200	12	1,620	3.7	5.0	5	56.9	24.1	32.8	27.5

Note: $\text{gpm/ft}^2 = 2.45\ \text{m}^3/\text{hr/m}^2$
gallon = $0.0038\ \text{m}^3$
lb. = 0.454 kg

Filter Column cross section area is 4.5 sq.ft. ($0.42\ \text{m}^2$)
In S-17 a significant amount of solids in the column leaked out the bottom before backwashing.

TABLE NO. A-4

HIGH RATE FILTRATION STUDY

FILTER PERFORMANCE-RDWS

Run No.	Flux Rate (gpm/ft^2)	Poly Feed (mg/l)	Alum Feed (mg/l)	Terminal Head Loss (ft)	Length of Run (hr)	Total Volume Filtered (gal)	Backwash Water			Air		Suspended Solids Mass Balance Analysis			
							Length (min)	Total Volume (gal)	% Total Water Filtered	Rate scfm/ft^2	Length (min)	Total S.S. Influent (lbs)	Total S.S. Effluent (lbs)	Calculated Removed in Column (lbs)	Recovered in Backwash (lbs)
D-1	8	0	0	5.3	2.5	5,400	14	980	18.1	4.0	6	5.7	2.2	3.5	
D-2	8	0	0	9.5	6.0	12,960	13	1820	14.0	4.0	7	13.2	4.4	8.8	
D-3	8	0	0	9.5	6.0	12,960	10	1600	12.3	4.0	6	13.0	3.9	9.1	
D-4	8	0	0	10.5	7.0	15,120	-	-	-	-	-	18.2	4.8	13.4	
D-5	12	0.5	0	9.5	4.0	12,960	15	2400	18.5	4.0	6	19.8	6.2	13.6	
D-6	12	0.5	0	9.5	6.0	19,440	20	3200	16.5	4.0	10	18.7	6.0	12.7	
D-7	12	0.5	0	11.2	5.0	16,200	-	-	-	-	-	21.7	6.9	14.8	
D-8	12	0.5	0	12.1	4.0	12,960	15	1050	8.1	4.0	6	19.5	7.8	11.7	
D-9	12	0.5	0	9.5	4.0	12,960	15	1050	8.1	4.0	6	15.7	4.8	10.9	
D-10	12	0.5	0	10.5	8.0	25,920	-	-	-	-	-	13.6	3.2	10.4	
D-11	12	0.5	0	13.8	5.0	16,200	16	1780	11.0	4.0	6	13.8	3.5	10.3	
D-12	12	0.5	0	13.8	6.0	19,440	16	1780	9.2	4.0	6	16.4	8.3	8.1	
D-13	12	0.5	0	6.6	7.0	22,680	26	1900	8.4	4.0	6	9.5	2.8	6.7	
D-14	12	0.5	0	13.1	4.0	12,960	25	1320	10.2	4.0	7	14.2	4.3	9.9	
D-15	12	0.5	10	13.8	6.0	19,440	25	1980	10.2	4.0	12	23.8	9.6	14.2	
D-16	12	0.5	10	13.1	6.0	19,440	20	2300	11.8	4.0	6	20.7	5.2	15.5	
D-17	12	0.5	10	12.1	8.0	25,920	20	1680	6.5	4.0	10	34.3	12.1	23.2	
D-18	12	0.5	10	12.1	8.0	25,920	14	1625	6.3	4.0	6	36.2	15.8	20.4	
D-19	12	0.5	10	13.8	8.0	25,920	24	2790	10.8	5.0	6	29.3	9.7	19.6	
D-20	16	0.5	10	9.5	4.0	17,280	24	2790	16.1	5.0	6	22.5	10.2	12.3	
D-21	16	0.5	10	10.5	6.0	25,920	15	2100	8.1	4.0	6	41.9	18.4	23.5	
D-22	12	0	25	13.8	8.0	25,920	24	2670	10.3	5.0	6	25.1	8.0	17.1	
D-23	16	0	19	10.5	4.0	17,280	21	2570	14.9	5.0	7	27.8	11.7	16.1	
D-24	12	1.0	0	10.5	6.0	19,440	15	2100	10.8	4.0	6	27.1	12.2	14.9	
D-25	16	0.5	0	10.5	4.0	17,280	15	1620	9.4	5.0	6	17.4	6.2	11.2	
D-26	12	0	0	12.1	8.0	25,920	15	1620	6.3	5.0	6	21.8	8.4	13.4	11.6
D-27	16	0.5	30	8.5	3.0	12,960	15	1620	12.5	5.0	6	16.4	3.2	13.2	13.7
D-28	16	5	15	12.1	6.0	25,920	10	1350	5.2	5.0	2	30.9	14.9	16.0	12.3
D-29	12	1.0	10	11.2	5.0	16,200	10	1350	8.3	5.0	2	19.7	7.5	12.2	-

TABLE A-5. FILTRATION COMPOSITE CHARACTERISTICS

Run No.	SS			BOD			COD			FCOD		
	Pi (mg/l)	Fi (mg/l)	Fe (mg/l)	Pi (mg/l)	Fi (mg/l)	Fe (mg/l)	Pi (mg/l)	Fi (mg/l)	Fe (mg/l)	Pi (mg/l)	Fi (mg/l)	Fe (mg/l)
S-4A	232	216	64	188	190	93	499	465	267	224	189	172
S-4B	132	116	54	130	113	80	344	310	206	164	151	146
S-5	248	268	100	240	220	130	483	448	204	178	157	148
S-6	380	388	112	235	235	133	551	534	258	228	155	142
S-7	236	204	96	222	180	160	449	335	272	159	109	180
S-8	132	148	56	100	111	113	212	220	140	76	93	85
S-9	-	-	-	-	-	-	-	-	-	-	-	-
S-10	184	140	47	238	173	138	359	355	246	180	175	175
S-11	92	88	21	86	83	52	175	166	114	79	74	88
S-12	136	156	60	76	68	39	175	175	92	48	44	48
S-13	216	192	124	136	123	96	357	340	235	90	95	86
S-14	212	200	74	88	81	35	258	250	129	85	69	73
S-15	196	182	98	125	117	83	195	263	216	64	68	76
S-16	116	-	48	75	79	45	205	202	119	76	79	104
S-17	246	206	104	127	141	93	392	406	274	225	230	225
S-18	230	186	111	85	85	50	311	263	241	118	110	153
D-25	116	144	56	114	109	76	306	244	178	116	136	166
S-26	148	132	94	155	145	105	307	274	166	141	124	128
S-27	-	-	-	-	-	-	-	-	-	-	-	-
S-28	-	152	72	-	150	134	-	362	274	-	191	208
S-29	144	104	81	-	140	90	321	306	210	203	203	195

TABLE A-6. BOD, FBOD, UBOD COMPOSITES COMPARISON

	Filter Influent			Filter Effluent			Removals		
Run No.	BOD (mg/l)	FBOD (mg/l)	UBOD (mg/l)	BOD (mg/l)	FBOD (mg/l)	UBOD (mg/l)	BOD (%)	FBOD (%)	UBOD (%)
S-4B	113	38	255	80	34	235	29	11	8
S-5	220	83	600	130	78	345	41	6	42
S-6	235	102	515	133	95	280	43	7	46
S-7	180	76	-	160	103	-	11	0	-
S-8	111	39	395	113	39	330	0	0	16
S-10	173	117	-	138	124	-	20	0	-
S-11	83	23	145	52	17	88	37	26	39
S-12	68	18	143	39	12	90	43	33	37
S-13	123	61	565	96	60	370	22	2	35
S-14*	-	-	-	-	-	-	-	-	-
S-15	117	45	275	83	44	190	29	2	31
S-16	79	25	267	45	38	194	43	0	27
S-17	141	48	-	93	47	-	34	2	-
S-18	85	34	-	50	30	-	41	12	1
D-28	150	85	-	134	88	-	11	0	-
D-29	140	68	340	90	84	150	36	0	56

* Composite samples were contaminated for S-14.

TABLE A-7. FBOD GRAB SAMPLE AVERAGES

Run No.	Plant Influent (mg/l)	Filter Influent (mg/l)	Filter Effluent (mg/l)
S-4A	86	81	86
S-4B	51	51	50
S-5	100	99	94
S-6	107	105	92
S-7	111	120	129
S-8	47	45	45
S-9	53	44	49
S-10	108	103	125
S-11	45	39	41
S-12	30	18	12
S-13	88	90	87
S-14	67	59	73
S-15	63	72	63
S-16	31	33	24

TABLE A-8. VSS COMPOSITE RESULTS

	VSS			VSS/SS			VSS Removals		
Run No.	Pi (mg/l)	Fi (mg/l)	Fe (mg/l)	Pi (%)	Fi (%)	Fe (%)	Screen (%)	Filter (%)	System (%)
S-4A	180	176	64	78	82	100	2	64	64
S-4B	120	92	50	91	79	93	23	46	58
S-5	184	184	68	74	69	68	0	63	63
S-6	252	232	68	66	60	61	8	71	73
S-7	176	148	88	75	73	92	16	41	50
S-8	84	92	36	64	62	64	-	61	-
S-9	-	-	-	-	-	-	-	-	-
S-10	164	140	47	89	100	100	15	66	71
S-11	78	72	16	85	82	76	8	78	79
S-12	86	68	54	63	43	90	21	21	37
S-13	148	132	92	69	69	74	11	30	38
S-14	188	148	60	89	74	81	21	59	68
S-15	140	132	92	71	73	94	6	30	34
S-16	54	-	32	47	-	67	-	-	41
S-17	198	158	58	80	77	48	20	63	71
S-18	154	110	61	67	59	55	29	45	56
D-29	120	70	66	83	67	81	42	6	45

TABLE A-9. BACKWASH COMPOSITE CHARACTERISTICS

Run No.	SS mg/l	VSS mg/l	BOD mg/l	FBOD mg/l	UBOD mg/l	COD mg/l	FCOD mg/l	Set. S. ml/l
S-4A	256	200	233	25	875	4089	65	-
S-4B	348	194	250	25	1275	3874	47	-
S-5	640	420	310	34	1280	957	70	-
S-6	780	440	220	35	920	732	52	-
S-7	252	204	130	16	-	277	42	-
S-8	140	96	168	33	800	649	64	-
S-9	580	440	351	20	1750	660	66	-
S-10	2715	1895	1300	67	-	3025	110	80
S-11	1520	1160	955	98	1420	1820	44	65
S-12	770	510	794	25	>530	1659	57	60
S-13	2825	1585	1113	25	4160	3099	60	57
S-14	2110	1340	476	-	1140	2540	48	60
S-15*	4064	2508	1840	53	2720	1961	117	90
S-16	1990	1150	>680	27	3520	2484	76	80
S-17	2372	1536	1347	33	-	2546	230	60
S-18	2810	1640	850	34	-	3200	215	66
D-26	1030	-	445	-	-	1234	54	-
D-27	2440	-	1340	50	-	2754	121	80
D-28	1820	-	1013	43	-	2163	87	85
D-29	3570	2770	1800	183	-	4092	199	100

* Composite taken from every sample instead of every 30 seconds sample.

NOTE: S-4 through S-9 filter runs were ended before solids penetrated through the filter and backwash values are abnormally low and not used in averages.

TABLE A-10. BACKWASH SLUDGE TESTING RESULTS

Test No.	SDI	Filter Leaf test-250 ml wet cake	 dry cake	 % dry	Settleable Solids ml/l	
D-27	3.1	1.26 gm	.48 gm	38.0	-	
D-28	2.1	.78	.25	32.0	1503	
D-29	3.6	2.24	.69	30.8	-	
S-6	-	-	-	-	-	
S-7	-	.21	.10	52.4	-	
		.21	.10	47.6*		
S-8	1.8	1.54	.37	23.7	110	78.6%
		1.03	.2	25.2*		
S-9	-	.48	.16	33.3	476	82.1%
S-10	3.4	1.98	.84	42.4	-	
S-11	2.3	-	-	-	-	
S-12	1.3	.80	.28	35.0	-	
S-14	3.5	1.30	.34	26.0	-	
S-15	4.5	2.3	.86	37.4	-	
S-16	2.5	1.8	.54	30.0	-	

TABLE A-10. (Continued) BACKWASH SLUDGE TESTING RESULTS

Filtration Sludge Buchner Funnel Results

Test No.	sec / ml	15	30	40	45	60	75	90	120	150	180	240	250	300	430
D-27		58	88	-	108	123	135	145	-	-					
D-28		-	70	-	-	100	-	122	140	150					
D-29		-	60	-	-	80	-	95	107	117					
S-6		76	99	-	119	137	150								
S-7		108	142	-	149										
S-8		-	-	62	-	-	-	-	92	-	-	120	-	-	150
S-9		-	115	-	-	145	-	150							
S-10		-	35	-	-	53	-	-	68	-	80	91	-	99	
S-11		-	46	-	-	59	-	-	76	-	90	-	98		
S-12		65	10	-	117	127	135	142							
S-14		120	150												
S-15		-	55	-	-	75	-	90	100	107					
S-16		40	70	-	92	108	115	120							

TABLE A-11. CADMIUM REMOVAL BY HRF TREATMENT

Filter Run No.	Cd Concentration				Cd Removal			Cd Mass Balance Analysis			
	Pi (ug/l)	Fi (ug/l)	Fe (ug/l)	Backwash (ug/l)	Screen (%)	Filter (%)	System (%)	Fi (gm)	Fe (gm)	Calculated Removal (gm)	Backwash Recovery (gm)
Prelim.	35.	--	15.	480.	--	--	57	--	--	--	--
Prelim.	35.	--	15.	150.	--	--	57	--	--	--	--
S4-A	35.	--	6.2	12.	--	--	82	--	0.10	0.47*	0.11
S4-B	8.7	--	3.1	21.	--	--	64	--	0.15	0.27*	0.16
S5	18.	--	14.	16.	--	--	22	--	0.23	0.06*	0.15
S6	3.4	--	3.4	14.	--	--	--	--	0.06	--*	--
S7	7.8	44.	7.8	6.4	--	82	--	1.08	0.19	0.89	--
S8	3.0	18.	12.	50.	--	33	--	0.50	0.33	0.17	--
S9	--	--	--	7.4	--	--	--	--	--	--	0.05
S10	76.	38.	5.4	5.4	50	86	93	3.42	0.49	2.93	0.03
S11	0.7	0.7	1.0	1.4	--	--	--	--	--	--	0.006
S12	1.0	2.0	0.6	44.	--	70	40	0.13	0.04	0.09	0.22
S13	20.	30.	10.	190.	--	67	50	3.19	1.06	2.13	1.16
S14	7.6	11.5	5.7	48.	--	50	25	0.56	0.28	0.28	0.15
S15	9.0	8.5	4.8	250.	6	44	47	1.11	0.63	0.48	0.78
S16	5.0	3.7	3.2	80.	26	14	36	0.24	0.21	0.03	0.25
S17	95.0	82.0	52.0	1130.	14	37	45	10.06	6.38	3.68	5.39
S18	22.0	15.0	4.8	86.	32	68	78	2.45	0.78	1.67	0.51
D29	9.4	7.0	5.8	250	26	17	38	0.43	0.36	0.07	--

* Calculated by Pi-Fe.

Pi - plant influent, Fi - filter influent, Fe - filter effluent

TABLE A-12. CHROMIUM REMOVAL BY HRF TREATMENT

Filter Run No.	Cr Concentration				Cr Removal			Cr Mass Balance Analysis			
	Pi (mg/1)	Fi (mg/1)	Fe (mg/1)	Backwash (mg/1)	Screen (%)	Filter (%)	System (%)	Fi (gm)	Fe (gm)	Calculated Removal (gm)	Backwash Recovery (gm)
Prelim.	6.0	--	0.29	30.0	--	--	95	--	--	--	--
Prelim.	6.0	--	1.9	9.0	--	--	68	--	--	--	--
S4-A	0.55	--	0.33	0.41	--	--	40	--	5.4	3.6*	3.8
S4-B	0.35	--	0.20	0.50	--	--	43	--	9.8	7.3*	3.8
S5	0.90	--	0.70	1.50	--	--	22	--	11.4	3.2*	13.9
S6	0.56	--	0.26	0.60	--	--	54	--	4.3	5.0*	--
S7	0.72	0.60	0.56	0.56	17	7	22	14.5	13.6	0.9	--
S8	0.31	0.30	0.21	0.55	3	30	32	8.2	5.9	2.3	--
S9	--	--	--	0.40	--	--	--	--	--	--	2.5
S10	0.20	0.25	0.35	0.10	--	--	--	--	--	--	0.6
S11	0.10	0.10	0.05	0.90	--	50	50	10.0	5.0	5.0	3.7
S12	0.10	0.15	0.10	1.2	--	33	--	10.0	6.4	3.6	6.1
S13	0.5	0.5	0.5	4.2	--	--	--	--	--	--	25.8
S14	0.35	0.31	0.15	2.8	11	52	57	15.0	7.3	7.7	8.7
S15	0.38	0.30	0.17	5.0	21	43	55	39.0	22.2	16.8	15.5
S16	0.33	0.28	0.10	4.0	15	64	70	18.2	6.4	11.8	12.4
S17	0.65	0.55	0.35	4.75	15	36	46	67.6	43.1	24.5	22.7
S18	0.40	0.35	0.20	4.05	13	43	50	76.7	55.4	21.3	24.1
D29	0.49	0.47	0.34	6.3	4	28	31	28.6	20.9	7.7	--

* Calculated by Pi-Fe.
Pi - plant influent, Fi - filter influent, Fe - filter effluent

TABLE A-13. COPPER REMOVAL BY HRF TREATMENT

Filter Run No.	Cu Concentration Pi (mg/l)	Cu Concentration Fi (mg/l)	Cu Concentration Fe (mg/l)	Cu Concentration Backwash (mg/l)	Cu Removal Screen (%)	Cu Removal Filter (%)	Cu Removal System (%)	Cu Mass Balance Analysis Fi (gm)	Cu Mass Balance Analysis Fe (gm)	Cu Mass Balance Analysis Calculated Removal (gm)	Cu Mass Balance Analysis Backwash Recovery (gm)
Prelim.	0.6	--	0.37	4.4	--	--	38	--	--	--	--
Prelim.	0.6	--	0.37	1.5	--	--	38	--	--	--	--
S4-A	0.32	--	0.18	0.36	--	--	44	--	2.9	2.7*	3.3
S4-B	0.26	--	0.16	0.58	--	--	38	--	7.8	5.0*	4.4
S5	0.44	--	0.28	0.86	--	--	36	--	4.6	2.7*	8.0
S6	0.44	--	0.20	0.68	--	--	55	--	3.3	4.1*	--
S7	0.68	0.52	0.54	0.40	24	--	21	--	--	--	--
S8	0.40	0.42	0.20	0.94	--	52	50	11.8	5.4	6.4	--
S9	--	--	--	0.70	--	--	--	--	--	--	4.4
S10	0.34	0.38	0.34	0.10	--	11	--	34.1	30.4	3.7	0.6
S11	0.10	0.12	0.06	1.14	--	50	40	11.8	5.9	5.9	1.0
S12	0.14	0.18	0.08	1.66	--	56	43	11.8	5.4	6.4	8.5
S13	0.36	0.44	0.30	6.0	--	32	17	46.8	31.8	15.0	36.8
S14	0.32	0.32	0.16	3.0	--	50	50	15.9	7.7	8.2	9.3
S15	0.34	0.28	0.18	5.4	18	36	47	36.8	23.6	13.2	16.7
S16	0.22	0.20	0.14	3.4	9	30	36	13.2	9.1	4.1	10.5
S17	0.56	0.48	0.26	6.6	14	46	54	59.0	31.8	27.2	31.5
S18	0.40	0.40	0.22	4.4	--	45	45	65.4	35.9	29.5	26.2
D29	0.30	0.30	0.20	5.4	--	33	33	18.6	12.2	6.4	--

*** Calculated by Pi-Fe.**

Pi - plant influent, Fi - filter influent, Fe - filter effluent

TABLE A-14. LEAD REMOVAL BY HRF TREATMENT

Filter Run No.	Pb Concentration Pi (mg/l)	Pb Concentration Fi (mg/l)	Pb Concentration Fe (mg/l)	Pb Concentration Backwash (mg/l)	Pb Removal Screen (%)	Pb Removal Filter (%)	Pb Removal System (%)	Pb Mass Balance Analysis Fi (gm)	Pb Mass Balance Analysis Fe (gm)	Pb Mass Balance Analysis Calculated Removal (gm)	Pb Mass Balance Analysis Backwash Recovery (gm)
Prelim.	1.28	--	0.50	5.20	--	--	61	--	--	--	--
Prelim.	1.28	--	0.44	2.45	--	--	66	--	--	--	--
S4-A	0.33	--	0.12	0.65	--	--	64	--	2.0	3.4*	6.0
S4-B	0.19	--	0.03	0.95	--	--	84	--	1.5	7.8*	7.2
S5	0.60	--	0.30	1.80	--	--	50	--	4.9	4.9*	16.7
S6	1.00	--	0.40	1.60	--	--	60	--	6.5	9.9*	--
S7	1.20	1.00	1.00	1.40	--	--	17	--	--	--	--
S8	0.40	0.40	0.20	1.10	--	50	50	11.1	5.6	5.5	--
S9	--	--	--	0.60	--	--	--	--	--	--	3.8
S10	0.20	0.20	0.20	0.20	--	--	--	--	--	--	1.2
S11	0.20	0.20	0.10	1.6	--	50	50	19.6	9.8	9.8	6.6
S12	0.20	0.20	0.10	2.5	--	50	50	13.1	6.5	6.6	12.8
S13	0.88	1.06	0.42	11.6	--	60	52	112.7	44.6	68.1	71.1
S14	0.7	0.7	0.4	5.3	--	43	43	34.3	19.6	14.7	16.4
S15	1.2	0.8	0.5	14.0	33	38	58	104.6	52.3	52.3	43.4
S16	0.7	0.5	0.2	8.5	29	60	71	32.7	13.1	19.6	26.4
S17	0.8	0.7	0.4	7.6	13	40	50	85.8	49.1	36.7	36.3
S18	0.6	0.5	0.3	10.0	17	43	50	81.8	49.1	32.7	60.0
D29	0.8	0.4	0.3	13.0	50	25	63	24.5	18.4	6.1	--

* Calculated by Pi-Fe.
Pi - plant influent, Fi - filter influent, Fe - filter effluent

TABLE A-15. MERCURY REMOVAL BY HRF TREATMENT

Filter Run No.	Hg Concentration Pi (ug/l)	Fi (ug/l)	Fe (ug/l)	Backwash (ug/l)	Hg Removal Screen (%)	Filter (%)	System (%)	Hg Mass Balance Analysis Fi (gm)	Fe (gm)	Calculated Removal (gm)	Backwash Recovery (gm)
Prelim.	2.2	--	2.2	5.2	--	--	--	--	--	--	--
Prelim.	2.2	--	0.4	4.2	--	--	82	--	--	--	--
S4-A	0.8	--	0.2	2.8	--	--	75	--	0.003	0.010*	0.026
S4-B	0.2	--	1.0	1.0	--	--	50	--	--	--	0.008
S5	0.2	--	1.2	0.8	--	--	--	--	--	--	0.007
S6	2.8	--	1.4	3.6	--	--	50	--	0.023	0.023*	--
S7	2.2	1.7	1.2	2.7	23	29	45	0.042	0.029	0.013	--
S8	0.7	0.7	0.4	2.4	--	43	43	0.019	0.011	0.008	--
S9	--	--	--	1.0	--	--	--	--	--	--	0.006
S10	0.4	0.4	0.5	0.2	--	--	--	--	--	--	0.001
S11	0.1	0.1	<0.1	1.	--	--	--	--	--	--	0.004
S12	0.3	0.3	0.2	1.0	--	33	33	0.020	0.013	0.007	0.005
S13	0.5	1.1	0.4	1.5	--	64	20	0.117	0.043	0.074	0.009
S14	0.5	0.9	0.3	0.1	--	67	40	0.044	0.015	0.029	0.0003
S15	0.6	0.7	0.3	0.7	--	57	50	0.092	0.039	0.053	0.002
S16	0.9	1.3	1.0	0.7	--	23	--	0.085	0.065	0.020	0.002
S17	1.2	0.7	0.2	1.2	--	71	83	0.086	0.025	0.061	0.006
S18	3.1	2.8	0.8	0.6	10	71	74	0.458	0.131	0.327	0.004
D29	1.6	1.8	1.0	2.3	--	44	38	0.110	0.061	0.049	--

* Calculated by Pi-Fe

Pi - plant influent, Fi - filter influent, Fe - filter effluent

TABLE A-16. NICKEL REMOVAL BY HRF TREATMENT

Filter Run No.	Ni Concentration				Ni Removal			Ni Mass Balance Analysis			
	Pi (mg/l)	Fi (mg/l)	Fe (mg/l)	Backwash (mg/l)	Screen (%)	Filter (%)	System (%)	Fi (gm)	Fe (gm)	Calculated Removal (gm)	Backwash Recovery (gm)
Prelim.	0.80	--	0.53	1.48	--	--	34	--	--	--	--
Prelim.	0.80	--	0.41	1.48	--	--	49	--	--	--	--
S4-A	0.28	--	0.23	0.05	--	--	18	--	3.8	0.8*	0.5
S4-B	0.22	--	0.32	0.046	--	--	--	--	--	--	0.4
S5	0.50	--	0.57	0.20	--	--	--	--	--	--	1.9
S6						sample lost					
S7						sample lost					
S8	0.15	0.077	0.10	0.10	49	--	33	--	--	--	--
S9	--	--	--	0.10	--	--	--	--	--	--	0.6
S10	0.25	0.30	0.15	0.15	--	50	40	27.0	13.5	13.5	0.9
S11	0.24	0.27	0.22	0.105	--	19	8	26.5	21.6	4.9	0.4
S12	0.078	0.096	0.078	0.19	--	19	--	6.3	5.1	1.2	1.0
S13	0.36	0.18	0.10	0.56	50	44	72	19.1	10.6	8.5	3.4
S14	0.10	0.12	0.06	0.24	--	50	40	5.9	2.9	3.0	0.8
S15	0.20	0.18	0.16	0.58	10	11	20	23.5	20.9	2.6	1.8
S16	0.16	0.10	0.12	0.34	38	--	25	--	--	--	1.1
S17	0.35	0.15	0.10	0.40	57	33	71	18.4	12.3	6.1	1.9
S18	0.25	0.25	0.20	0.25	--	20	20	40.9	32.7	8.2	1.5
D29	0.16	0.14	0.10	0.46	13	29	38	8.6	6.1	2.5	--

* Calculated by Pi-Fe
Pi - plant influent, Fi - filter influent, Fe - filter effluent

TABLE A-17. ZINC REMOVAL BY HRF TREATMENT

Filter Run No.	Zn Concentration				Zn Removal			Zn Mass Balance Analysis			
	Pi (mg/l)	Fi (mg/l)	Fe (mg/l)	Backwash (mg/l)	Screen (%)	Filter (%)	System (%)	Fi (gm)	Fe (gm)	Calculated Removal (gm)	Backwash Recovery (gm)
Prelim.	1.00	--	0.06	3.68	--	--	94	--	--	--	--
Prelim.	1.00	--	0.55	1.08	--	--	45	--	--	--	--
S4-A	0.57	--	0.29	0.43	--	--	49	--	4.7	4.6*	4.0
S4-B	0.46	--	0.39	0.74	--	--	15	--	19.1	3.5*	5.6
S5	0.50	--	0.32	0.90	--	--	36	--	5.2	3.0*	8.4
S6	0.78	--	0.32	1.06	--	--	59	--	5.2	7.6*	--
S7	0.48	0.40	0.32	0.36	17	20	33	9.8	7.8	2.0	--
S8	0.44	0.48	0.30	0.90	--	38	32	13.3	8.3	5.0	--
S9	--	--	--	0.70	--	--	--	--	--	--	4.4
S10	0.13	0.12	0.13	0.07	8	--	--	--	--	--	0.4
S11	0.12	0.12	0.09	1.80	--	25	25	11.8	8.8	3.0	7.5
S12	0.19	0.27	0.17	2.2	--	37	11	17.7	11.1	6.6	11.2
S13	0.54	0.65	0.43	5.8	--	34	20	69.1	45.7	23.4	35.6
S14	0.49	0.55	0.39	3.0	--	29	20	27.0	19.1	7.9	9.3
S15	0.51	0.41	0.27	7.9	20	34	47	53.6	35.3	18.3	24.5
S16	0.36	0.35	0.18	4.2	3	49	50	22.9	11.8	11.1	13.0
S17	0.80	0.70	0.42	7.7	13	40	48	85.8	51.5	34.2	36.7
S18	0.57	0.51	0.31	6.5	11	39	46	83.4	50.7	32.7	38.7
D29	0.46	0.43	0.37	6.0	7	14	20	26.4	22.7	3.7	--

* Calculated by Pi-Fe.

Pi - plant influent, Fi - filter influent, Fe - filter effluent

TABLE A-18. ARSENIC REMOVAL BY HRF TREATMENT

Filter Run No.	As Concentration				As Removal			As Mass Balance Analysis			
	Pi (mg/l)	Fi (mg/l)	Fe (mg/l)	Backwash (mg/l)	Screen (%)	Filter (%)	System (%)	Fi (gm)	Fe (gm)	Calculated Removal (gm)	Backwash Recovery (gm)
S8	3.5	4.6	2.2	1.2	--	52	37	0.128	0.061	0.067	--
S9	--	--	--	0.5	--	--	--	--	--	--	0.003
S10	3.1	4.0	4.0	0.5	--	--	--	--	--	--	0.003
S11	6.4	6.4	7.2	0.8	--	--	--	--	--	--	0.004
S12	11.	17.	11.	41.	--	35	--	1.11	0.72	0.39	0.21
S13	14.	11.	14.	96.	21	--	--	--	--	--	0.59

Pi - plant influent, Fi - filter influent, Fe - filter effluent

TABLE A-19. HRF REMOVAL OF COLIFORM BACTERIA

				Total/Fecal Coliforms		
Filter Run No.	Flux (gpm/ft^2)	Poly Feed (mg/l)	Alum Feed (mg/l)	Plant Influent (10^6/100 ml)	Filter Effluent (10^6/100 ml)	Total % Removal
D-5	12	0.5	0	.0.3/	2.8	-
D-8	12	0.5	0	11.0/	6.3	43
D-11	12	0.5	0	3.3/	4.9	-
D-14	12	0.5	0	1.1/	4.9	-
D-17	12	0.5	10	160. /	240.	-
D-20	16	0.5	10	35. /	240.	-
D-23	16	0	19	54. /	35.	35
S-1A	16	0	0	240. /4.5	35 /14.	85/-
S-1B	16	0	0	22. /1.7	1.7/1.8	13/-
S-2B	16	0	0	240 /4.	240. /1.3	-/67
S-2C	16	0	0	- /6.2	- /0.5	-/92
S-3A	16	8 (liquid)	0	-	- /3.8	-

NOTES:

1. Composite samples taken for coliform analysis only; chemical samples were taken separately.
2. Coliforms analyzed by multiple tube technique (confirmed results), fecals incubated at 44.5°C.
3. Fecal coliforms not tested in RDWS runs (D5-23).

TABLE A-20. TEST STORM CHARACTERISTICS*

Storm No. **	Duration (hr.)	Accumulation(in.)	Intensity (in/hr)
S-5	3	0.07	0.02
S-6	1	0.17	0.17
S-7	14	0.48	0.03
S-8	7	0.52	0.07
S-9	13	0.10	0.008
S-10	21	1.54	0.07
S-11	6	0.19	0.03
S-12	9	0.57	0.06
S-13	13	1.15	0.09
S-14	16	3.15	0.20
S-15	13	0.74	0.06
S-16	19	1.92	0.10
S-17	4	0.24	0.06
S-18	25	1.68	0.07

* Data obtained from the National Weather Service, La Guardia Station, New York City

** Dates of each storm tested are indicated on Table A-1.

1 in. = 2.54 cm

TABLE A-21. CONVERSION FACTORS ENGLISH TO METRIC UNITS

English Unit	Abbr.	Multiplier	Abbr.	Metric Unit
Acre	acre	0.405	ha	hectare
Foot (feet)	ft	0.305	m	meter(s)
Gallon(s)	gal	3.785	l	liter(s)
		3.785×10^{-3}	m^3	cubic meter(s)
Gallons per day per square foot	gpd/ft^2	0.041	$m^3/day/m^2$	cubic meters per day per square meter
Gallons per minute per square foot	gpm/ft^2	2.45	$m^3/hr/m^2$	cub meters per hour per square meter
Gallons per minute	gpm	0.0631	l/s	liters per second
Horsepower	hp	0.746	kW	kilowatts
Inch (es)	in.	2.54	cm	centimeter
Million gallons per day	mgd	3,785	m^3/day	cubic meters per day
Parts per billion	ppb	1.0	ug/l	micrograms per liter
Parts per million	ppm	1.0	mg/l	milligrams per liter
Pound (s)	lb	0.454	kg	kilogram
		453.6	g	grams
Pounds per cubic foot	lb/ft^3	16.02	kg/m^3	kilograms per cubic meter
Pounds per square foot	lb/ft^2	4.88	kg/m^2	kilograms per sq. meter
Pounds per square inch	psi	0.0703	kg/cm^2	kilograms per sq. centimeter
Square foot	ft^2	0.0929	m^2	Square center
Square inch	in.^{2}	6.452	cm^2	square centimeter
Standard cubic feet per minute	scfm	1.699	m^3/hr	cubic meter per hour
Standard cub feet per minute per sq. foot	scfm/ft^2	0.305	$m^3/min/m^2$	cubic meters per minute per square meter
Ton (short)	ton	907.2	kg	kilograms
		0.907	metric ton	metric ton
Yard	yd	0.914	m	meter